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HOW CURRICULUM INFLUENCES STUDENT LEARNING

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The purpose of this chapter is to review research on how mathematics curriculum[1] influences student learning. Interestingly, there was not a similarly named chapter in the 1992 *Handbook of Research on Mathematics Teaching and Learning* (Grouws, 1992), suggesting that the mathematics curricula of the '70s and '80s and their relationship to student learning were not viewed as a significant object of scholarly investigation at the time. Most likely, this stance reflected the era more broadly, a time during which arithmetic—primarily computation—comprised the lion's share of work in the elementary years, and algebra—principally procedures for manipulating symbolic expressions—formed the majority of high school work in mathematics. In this milieu, textbooks were viewed primarily as a resource for problem sets: "Very few had references to mathematical concepts or principles and virtually none had problems from everyday life or from other fields" (Senk & Thompson, 2003 p. 9). The absence of a chapter on curriculum in the 1992 *Handbook* may also reflect the period in time—a time during which reformers focused on helping teachers create lessons based on activities found *outside* of commercial textbooks.[2] This tendency may have reflected a general disillusionment among mathematics educators with the textbooks available at the time most of which were developed by publishing companies and did not draw on research on how students learn mathematics (Ball & Feiman-Nemser, 1988).

Current interest in how curriculum materials influence student learning has been fomented by sev-

[1] As described later, we use the term curriculum broadly to include mathematics curriculum materials and textbooks, curriculum goals as intended by teachers, and the curriculum that is enacted in the classroom.

[2] Examples include Cognitively Guided Instruction (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989), replacement units, and manipulative-based programs.

eral policy shifts in mathematics education and educational research and practice more generally. First, the field has seen a sharp rise in curriculum development activity since the writing of the 1992 Handbook chapter—much of it in response to publication of the *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989). As states adopted standards that reflected the NCTM's vision, the publishing industry moved quickly to make adaptations to their textbooks. At the same time, the National Science Foundation (NSF) funded extensive curriculum development projects that produced an entirely new set of curriculum materials that entered the market in the mid- to late-nineties (referred to as "standards-based curricula"). This activity dwarfed even the explosion of curriculum development that occurred during the new math era of the late '50s and '60s (Usiskin, 1997).

These materials have generated particular interest of researchers because they embody an approach to mathematics teaching and learning that is qualitatively different from textbooks or instructional resources previously available. The standards-based curricula had a common set of design specifications that included alignment with the *Curriculum and Evaluations Standards for School Mathematics* (NCTM, 1989), heavy use of non-numeric representations (e.g., diagrams, manipulatives), an expanded content base (e.g., in elementary curricula, topics that go beyond traditional arithmetic to include statistics and graphing, geometry, and pre-cursors to algebraic reasoning), and extensive use of calculators. Moreover, in order to meet new goals for student learning (i.e., mathematical thinking, reasoning, problem solving, connecting, communicating, seeking evidence, and constructing arguments to make predictions and support conclusions), these new curricula de-emphasized paper-and-pencil skills and focused on students' active construction of and communication about solutions to challenging problems. A subset of these curricula also incorporated technologies (e.g., intelligent tutors) that were not previously available.

The kind of instructional experience supported by the standards-based curricula represented a substantial departure from conventional practice in the U.S. As summarized by Fey (1979) from three studies commissioned by the National Science Foundation (Stake & Easley, 1978; Suydam & Osborne, 1977; Weiss, 1978) and corroborated by the recent TIMSS study (NCES, 2003; Stigler & Hiebert, 2004), the majority of mathematics lessons in the U.S. involved extensive, teacher-directed explanation of new material followed by student seatwork on paper-and-pencil assignments with little or no discussion or exploration of concepts. As such, reformers cast these new curricula in the role of change agent with the hope that they would help teachers to transform their instruction from a focus on basic skills to conceptually based problems that require thinking, reasoning, problem solving and communication (Senk & Thompson, 2003). To others, however, these new curricula represented a swing of the pendulum too far toward an emphasis on the processes of doing mathematics to the detriment of time spent developing computational efficiency (Wu, 1997).

The standards-based era of curriculum development has been associated with increased vigor in the mathematics education community and an upsurge in research activity. Because the new curriculum materials and the standards documents on which they were based, offered a radically different vision of what it means to learn mathematics and consequently how it should be taught in the classroom, they prompted a substantial amount of research on the role of teachers in the standards-based classroom, as well as research on the relationship between teachers' beliefs and knowledge and their instructional practice. All of these studies are critical to the central argument of this chapter and our response to its driving question—How do curriculum materials influence student learning? As we detail below, the influence of curriculum materials is mediated by teachers and students interacting with those materials in classroom contexts.

A second policy shift, occurring in the late 1990s and early 2000s, catalyzed another research emphasis that raised different kinds of questions about the influence of curriculum materials on student learning: "Do these new materials work?" Because the passage of the *No Child Left Behind Act* restricted the use of federal monies to those programs backed by scientific evidence of student learning (NCLB, 2002), many curriculum developers became eager to "prove" the effectiveness of their materials. In addition, harsh criticism of education research and educational practices as not scientifically based led to calls for research on the effectiveness of educational programs in general, including innovative curricula such as the NSF-sponsored materials (Mosteller & Boruch, 2002; NRC, 2002; 2004). Finally, in response to perceived needs of practitioners to distinguish effective from non-effective programs, the US Department of Education established the *What Works Clearinghouse*. This Internet-based website features the results of research, that qualifies as scientifically based, on the outcomes of educational programs and curriculum materials, as measured by gains in student achievement. This climate of accountability led to a substantial number of studies that aimed to discern what students who were exposed to different kinds of curriculum materials learned. In

this chapter, we review both these effectiveness studies and the broader field of research on how teachers and students use curricula.

CONCEPTUAL ISSUES, DEFINITIONS, AND BOUNDARIES

The term *curriculum* has different meanings in different contexts. Therefore, we begin with a brief discussion of the term and its varied applications in order to clarify how we are using it in this chapter. In so doing, we present the framework that structures our discussion. We also discuss how the construct of *curriculum materials* or *textbooks* has evolved and shifted in educational discourse and, particularly in mathematics education. Finally, we specify the boundaries of our review.

Multiple Meanings of Curriculum

Very broadly, curriculum refers to the substance or content of teaching and learning—the "what" of teaching and learning (as distinguished from the "how" of teaching). Those who study curriculum frequently examine planned and unplanned components of what is taught or experienced in classrooms (Jackson, 1992). However, among educational decision makers, the term curriculum is often used to refer to expectations for instruction laid out in policy documents or frameworks. Currently, and in direct response to the recent flurry of curriculum material development, many mathematics education researchers and practitioners use the term *curriculum* to refer to the material resources designed to be used by teachers in the classroom, such as "standards-based curricula."

Research on teaching and curriculum, however, has revealed that a substantial difference exists between the curriculum as represented in instructional materials and the curriculum as enacted in the classroom by teachers and students. Curriculum theorists use a number of terms to distinguish between the curriculum outlined in a guide or set of materials and that enacted in the classroom. *Formal* (Doyle, 1992) or planned curriculum (Gehrke, Knapp, & Sirotnik, 1992), for example, refer to the goals and activities outlined by school policies or designed in textbooks or by teachers. The objectives set out in curriculum frameworks or state standards as well as those specified in scope and sequence charts in textbooks also represent formal curricula, sometimes referred to as the *institutional* or *intended* curriculum. The *enacted* curriculum refers to what actually takes place in the classroom (Gehrke et al., 1992). In order to identify the impact that the enacted curriculum has on students, researchers use terms such as the *experienced* (Gehrke et al., 1992) or *attained* (Valverde, Bianchi, Wolfe, Schmidt, & Houang, 2002) curriculum. It is worth noting that distinctions are infrequently made between the curriculum as outlined by policy makers or curriculum designers and the curriculum interpreted or intended by the teacher.

In our effort to examine the influence that curriculum materials have on student learning, we have found all these meanings of curriculum to be significant and interrelated, yet uniquely important. In short, the influence of curriculum materials on student learning is not straightforward and cannot be understood without examining the curriculum as designed by teachers and as enacted in the classroom. Drawing on our earlier work (Remillard,1999; Stein, Grover, & Henningsen, 1996), we have conceptualized these various meanings of curriculum as unfolding in a series of temporal phases from the printed page (*the written curriculum*), to the teachers' plans for instruction (*the intended curriculum*),[3] to the actual implementation of curricular-based tasks in the classroom (the *enacted* curriculum). (See Figure 8.1.)

Within and between certain of these phases, interpretative and interactive processes transform the curriculum. *Between* the written and intended phases, teachers bring their prior understandings, beliefs, and goals to bear on the written curriculum and, in the process, transform it into a form that they believe will be workable in the classroom. *Within* the enactment phase, the teacher and the students, in interaction with each other, bring the curriculum to life and, in the process, create something different than what could exist on the pages of the book or in the teacher's mind or lesson plan. While all of the phases have a bearing on student learning (the final triangle), the classroom activities that occur during the enactment phase most directly influence how students experience mathematics and what they learn (Carpenter & Fenemma, 1988; Wittrock, 1986). We have added return arrows from the enacted curriculum and student learning to the transformation processes between the written and intended curriculum to indicate that the enacted curriculum and teachers influence teachers' future interactions with written curriculum.

The oval in Figure 8.1 identifies possible factors that mediate the interpretive and interactive processes

[3] Our use of the term, "intended" differs from TIMSS' use of the term. TIMSS used "intended" to refer to what we call the "written" curriculum.

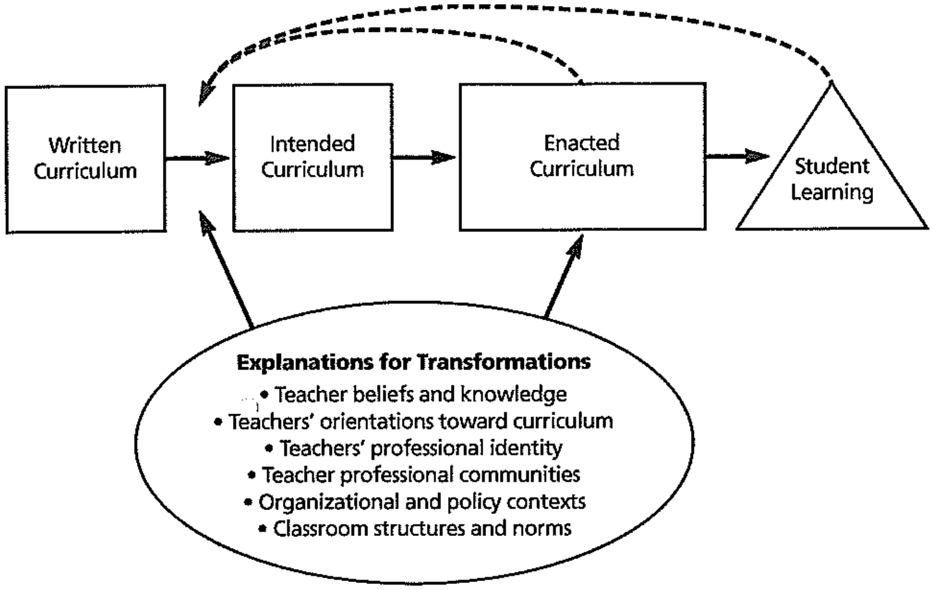


Figure 8.1 Temporal phases of curriculum use.

that occur within and between phases. A variety of studies, some specifically focused on curriculum use, others on the implementation of reform in general, have identified one or more of these factors as influencing how curriculum use unfolds. A number of researchers, for example, have explored the manner in which individual teacher characteristics and capacities, such as subject matter knowledge (Brophy, 1991, 2001; Stein, Baxter, & Leinhardt, 1990), beliefs (Cohen, 1990; Jennings, 1996; Putnam, 1992; Remillard, 1992; Spillane, 1999; Spillane & Jennings, 1997), and professional identity (Remillard & Bryans, 2004) influence how teachers understand and enact reform. Increasingly, studies—inside and outside of mathematics reform—have begun to suggest explanations for transformations that are external to the individual teacher. For example, research suggests that strong professional communities can help teachers to learn complex new ways of teaching (Cobb, McClain, de Silva Lamberg & Dean, 2003; Little & McLaughlin, 1993; Louis, Marks, & Kruse, 1996; Stein, Silver, & Smith, 1998) whereas teachers working in isolation are apt to continue to practice in the manner they always have. In addition, implementation of new programs and practices at the school level is influenced by organizational and policy contexts such as, the level of support from the principal (Berends, Kirby, Naftel, & McKelvey, 2001; Bodilly, 1998; Datnow, Hubbard, & Mehan, 2002; Fullan, 1991; Kirby, Behrends, & Naftel, 2001). Finally, factors central to the social organization of the school and classroom, including students, classroom structures, and norms (Doyle, 1983) can influence the curriculum transformation process.

The framework depicted in Figure 8.1 provides an organizing structure for the studies reviewed in this chapter. In *Section One*, we review research that has addressed the impact of curriculum materials on student learning. Many scholars and policymakers have (implicitly) conceptualized these studies as testing a (causal) relationship between the written curriculum (the first box in Figure 8.1) and student learning (the final triangle in Figure 8.1). The driving equation is, "Does curriculum X work?" with an emphasis on the written materials (not their enactment) as the intervention and a focus on student outcomes (usually achievement scores) as the indicator of what it means to work. After reviewing the findings of this research, we highlight the pros and cons of viewing the relationship between curriculum and student learning in this way; we then turn to the mediating relationships depicted in the figure to identify *how* curriculum influences student learning.

The studies reviewed in the next two sections begin to unpack how curriculum influences student learning by focusing on the transformations written curricula undergo as teachers engage with and use them in the classroom. In *Section Two* we review research on how teachers interpret curriculum materials which can be viewed as a discussion of the relationship between the written curriculum and the intended curriculum (the first and second boxes in Figure 8.1). In *Section Three* we review studies that have focused on what happens when curricular tasks are unleashed inside the classrooms; as such, this section focuses on studies falling within the box labeled enacted curriculum. The research reviewed in *Section Four* deals with studies that

aim to identify reasons for the variations uncovered in Sections Two and Three (i.e., why do teachers interpret and enact curriculum in different ways?) and thus can be seen as a discussion of the explanations that appear in the oval. Finally, in *Section Five* we review research on the relationship between the enacted curriculum and student learning (the final box and the final triangle of Figure 8.1). As such, Section Five also examines the question, "Does curriculum X work?" but this time the intervention is broadly conceived to include how teachers and students engage with the curriculum resource as well as the curriculum itself.

When considered together, the research conducted on the phases of curriculum use paints a complex picture of how curriculum influences student learning. More specifically, it points to the fallacy of assuming that the materials themselves are the primary agent in shaping opportunities for student learning and instead uncovers the important role played by the interpretive and interactive influences of teachers and students. Because they often represent the starting point for instruction, the materials are important and their influence merits substantial investigation; thus, they remain a focal point of this chapter. However, tracing *how* they are important necessarily takes one into the realm of teachers, students, and classrooms. Consequently, the reader will find overlaps between the research examined in this chapter and the chapter by Hiebert and Grouws on classroom teaching.

Curriculum Materials: An Evolving Construct

Because curriculum materials are a focal point of this chapter, we begin with a brief examination of what mathematics textbooks or curriculum materials are and how they and the way they are perceived have changed throughout the history of U.S. public education. Over the years texts and curriculum materials have varied in focus, style, philosophy and degree of comprehensiveness and have taken on different roles in the minds of teachers and administrators. While we use the terms *curriculum materials* and *textbook* (along with instructional resources and guides) somewhat interchangeably to refer to printed or electronic, often published, materials designed for use by teachers and students before, during, and after mathematics instruction, many teachers and mathematics educators draw sharp delineations between the two.

During the latter part of the 20th century, mathematics *textbooks* common to classrooms in the U.S. were viewed as a source of explanations and exercises for students to complete. The textbook played a central role in most mathematics classrooms and instruction was aimed at teaching students what they needed to know in order to complete the exercises and answer the questions in their books (Jackson, 1968).

Unlike the term mathematics textbook, the term mathematics *curriculum materials* often refers to instructional guides that place substantial emphasis on both pedagogy (the how of teaching) and mathematics (the what of teaching). To many, the term curriculum materials was used to connote something akin to an "anti-textbook" because these resources offered programs of instruction that rejected the notion that learning mathematics involved completing decontextualized exercises in a book. In contrast to textbooks, which were developed and marketed by commercial publishing companies, curriculum materials tended to be designed by mathematics experts and mathematics education researchers and, prior to the late 1990s, were sold independently to a fairly small market. For most standards-based curriculum materials, students' work during instruction involves investigative projects instead of exercises found on the pages of a "student textbook." Student textbooks are replaced by thin, often consumable, student workbooks that are designed to support students' investigative work. The centerpiece of most lessons is the thinking that is required to grapple with the investigative task; student work books are designed to support that thinking by providing a basis for recording, summarizing or reflecting on one's actions and thinking.

Curriculum material development played a central role in the "modern mathematics" period of the late 1950s and early '60s. During this time, numerous scientists and mathematicians were solicited to design instructional materials that would prepare the next generation of citizens to be scientifically competitive. The NSF played a major role in funding the development of the majority of these programs, often referred to as the "New Math."[4] The curriculum products of these content experts sought to place equal emphasis on "computational skill" and "understanding the basic concepts of mathematics and of their interrelationships, i.e., the structures of mathematics" (Begle, 1970, p. 1). Like texts of the past, these materials were designed with students (specifically talented students), not teachers, in mind. The consideration these developers gave to the teacher's role is less clear, but it is understood that they grossly "overestimated

[4] Specifically, the term New Math refers to the curriculum materials developed in the 1960s by the School Mathematics Study Group (SMSG). It is often used to refer to all reform-oriented mathematics materials produced during the period of modern mathematics reform.

the materials' independent educative power" and underestimated the influence of the teacher in their use (Cohen & Barnes, 1993, p. 215). As a result, the curriculum materials developed during the modern math period are frequently labeled as attempts to be "teacher proof."

Like the New Math materials, curriculum materials developed during the period of standards-based reform initiated in the early 1990's are also seen as a potential means for shifting instructional practices. Unlike the New Math, however, the role of the teacher is generally explicitly acknowledged in these materials; most include detailed pedagogical guidance for teachers and some include resources to support teacher learning. For example, *Investigations in Data, Number and Space*, an NSF-supported elementary curriculum, includes "Notes to Teachers" that explain the mathematical significance of the ideas that are featured in particular lessons and how students might think about those ideas and "Dialogue Boxes" that illustrate how a student discussion surrounding those ideas might unfold in the classroom. As such, these materials can be viewed as being written for teachers and their learning, rather than being written for direct consumption by students. Remillard (2000) refers to this approach to curriculum design as curricula speaking *to*, as opposed to speaking *through*, the teacher.

The expectation by NSF that curriculum developers distribute their materials through established commercial publishers has had far-reaching influences. Most standards-based materials have experienced unprecedented visibility and success in the commercial markets. At the same time, the final products reflect compromises reached between developers and publishers. And, ironically, curriculum materials developed independently are marketed and sold along side, and sometimes as extensions of, instructional materials and textbooks developed "in house." Thus, another result of the way standards-based curriculum materials have been marketed may be a blurring of distinct lines that—at one time—clearly differentiated them from conventional texts.

The role of curriculum materials has also been conceptualized differently—even within the same period of time. Some individuals view curriculum materials as a direct blueprint for instruction—a plan to be unerringly implemented. According to this view, material that appears on the written page of the curriculum is meant for faithful execution by teachers and students. Others view curriculum materials as a *resource* to be drawn upon by teachers as they construct lessons and units. This view suggests that complete fidelity of implementation is impossible because teachers will always bring their own frames of understanding and their knowledge of the local context to bear on how they use curricular materials. Inevitably, this view argues, teachers and students construct their own unique version of the curriculum—a version that necessarily springs from their goals, needs, and understandings (Remillard, 2005).

Literature Selection and Boundaries of this Review

In preparing this chapter, we reviewed research on the effects of mathematics curriculum materials or textbooks, both standards-based and conventional, on students and teachers available in peer-reviewed journals in addition to other sources such as research reports and edited volumes. A substantial portion of the research reviewed in this chapter was spurred by the wave of curriculum development supported by NSF and initiated after the publication of the NCTM *Standards* (1989). As noted earlier, the introduction of these curriculum materials to the public catalyzed substantial research activity—activity that was not matched by studies of conventional textbooks. The marked differences in the number of studies conducted on NSF-supported in contrast to conventional textbooks can be attributed to at least three reasons: a) NSF-supported curriculum developers were required by the funder to conduct evaluations and were sometimes provided with the funds to do so; b) the majority of NSF-supported curriculum developers were university faculty or researchers whose graduate students and colleagues conducted studies on the use of the new materials; and c) the research conducted by commercial publishing companies tended to be market driven, focusing on purchasing decisions rather than on measures of student outcomes or teacher use (NRC, 2004, pp. 25–28).

In an effort to orient the reader to the range of curriculum materials available in the U.S. during the time this chapter was written, we have identified the most well-known curriculum materials in Table 8.1. The first column identifies the full name of the text; the second column identifies the grade band for which the materials were developed. In the third column we identify the funder (if any and if known).

In the final column we indicate the category or group to which we have assigned the curriculum for

Table 8.1 Mathematics Curricula Commonly Used in U.S. Public Schools

Curriculum	Level	Funder (if any and if known)	Standards-based or Conventional
**Everyday Mathematics;* SRA/McGraw Hill	Elementary	NSF	Standards-based
**Investigations in Number, Data, and Space;* Scott Foresman	Elementary	NSF	Standards-based
**Math Advantage K–6;* Harcourt Brace	Elementary		Conventional
Math in My World; McGraw Hill	Elementary		Conventional
**Math K–5;* Scott Foresman/Addison Wesley	Elementary		Conventional
Math Land	Elementary		Standards-based
**Math Trailblazers;* Kendall/Hunt	Elementary	NSF	Standards-based
Number Power (supplemental)	Elementary	NSF	Standards-based
Opening Eyes to Mathematics; Visual Mathematics	Elementary		Standards-based
Saxon Math	Elementary		Conventional
Silver Burdett Ginn Math	Elementary		Conventional
SRA Math; McGraw Hill	Elementary		Conventional
**Connected Mathematics Project* (CMP); Prentice Hall	Middle School	NSF	Standards-based
Heath Mathematics Connections; DC Heath & Co.	Middle School		Conventional
Math Advantage; Harcourt Brace	Middle School		Conventional
Math Alive; Visual Mathematics	Middle School		Standards-based
**Mathematics: Applications & Connections;* Glencoe/McGraw Hill	Middle School		Conventional
**Mathematics in Context* (MiC); Holt, Rinehart, & Winston	Middle School	NSF	Standards-based
Mathematics Plus; Harcourt Brace & Co.	Middle School		Conventional
**MathScape: Seeing and Thinking Mathematically;* Glencoe/McGraw Hill	Middle School	NSF	Standards-based
**MathThematics* (STEM); McDougal Littell	Middle School	NSF	Standards-based
Middle Grades Math; Prentice Hall	Middle School		Conventional
Middle School Math; Scott Foresman/Adison Wesley	Middle School		Conventional
**Middle School Mathematics Through Applications Project* (MMAP; unpublished)	Middle School	NSF	Standards-based
Passport Series; McDougal-Littell	Middle School		Conventional
Pre-Algebra: An Integrated Transition to Algebra and Geometry; Glencoe/McGraw Hill	Middle School		
**Saxon Math*	Middle School		Conventional
Cognitive Tutor	Middle/High School		Standards-based
College Preparatory Mathematics (CPM)	High School		Standards-based
**Contemporary Mathematics in Context* (Core-Plus)	High School	NSF	Standards-based
**Interactive Mathematics Program (IMP);* Key Curriculum Press	High School	NSF	Standards-based
**Larson Series,* Grades 9–12; Houghton Mifflin/McDougal Littell	High School		Conventional
**MATH Connections: A Secondary Mathematics Core Curriculum Grades 9–12;* IT'S ABOUT TIME, Inc.	High School	NSF?	Standards-based
**Mathematics: Modeling Our World (MMOW/ARISE);* W.H. Freeman & Co.	9–12	NSF	Standards-based
**Systemic Initiative for Montana Mathematics and Science (SIMMS) Integrated Mathematics;* Kendall/Hunt	High School	NSF	Standards-based
**University of Chicago School Mathematics Project Integrated Mathematics, Grades 7–12*; Prentice Hall	Middle/High School	NSF, Amoco Foundation, Carnegie Corp. of New York, General Electric Foundation	Standards-based

*= Curriculum included in NRC panel report, *On Evaluating Curricular Effectiveness.*

the purposes of this chapter. Curriculum materials are identified as either "standards-based" or "conventional." *Standards-based curriculum materials* include the NSF-funded materials, curriculum materials that were inspired by documents that *preceded* the 1989 *Curriculum and Evaluation Standards* (e.g., AAAS's *Benchmarks for Scientific Literacy*; and NRC's *Everybody Counts*, and the draft version of the *Curriculum and Evaluation Standards for School Mathematics* that circulated in the mid-eighties), and, finally, curriculum materials that were driven by the ideas in the NCTM *Standards*, but not funded by the National Science Foundation (e.g., the *Cognitive Tutor*). *Conventional curriculum materials* include commercially developed textbooks with earlier editions that had been on the market prior to the release of the *Curriculum and Evaluation Standards*, editions that were not influenced by the earlier reform documents mentioned above. It should be noted that many of these publishers attempted to align the content of subsequent editions with the NCTM Standards after they appeared in 1989; however, this alignment was primarily accomplished through backward-mapping as opposed to using the *Standards* as a design template from the start, thereby giving these textbooks a substantially different "look and feel" than those materials that we label standards-based.

When we cite studies that explicitly involve one or more of the materials that appear in Table 8.1, we identify the curriculum by name. When overall statements are made regarding the characteristics or efficacy of various kinds of materials, we refer to the two general categories of standards-based or conventional.

Finally, the focus of our examination of the influence of curriculum on students is on classrooms—teachers and students. Thus, our discussion of curriculum materials centers on the resources and materials that teachers typically interact with as they plan and carry out their lessons. We have not included policy documents or the curriculum frameworks developed by districts or states in our review. In taking this approach, we do not, however, ignore the role that policy and organizational designs play in curriculum use. We recognize that state and local policy shape the manner in which teachers think about and use curriculum materials. We account for these contextual features primarily in our discussion of the explanations of how the curriculum is transformed between and within phases of enactment (see oval in Figure 8.1).

SECTION ONE: RESEARCH ON CURRICULUM MATERIALS AND STUDENT LEARNING

The *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) were created based on a broad consensus of professionals (teachers, mathematics educators, mathematicians, users of mathematics, etc.) and were framed in broad, easy-to-agree-with terms (EEPA, 1990). The curricular resources that were developed to embody them, however, offered much more detailed specification regarding what should be taught and how it should be taught, thereby providing concrete targets for critics of the Standards. As these new standards-based curriculum materials began to penetrate the market in the mid- to late-nineties, critics charged that they watered down important mathematical concepts, relied too heavily on real-life problems at the expense of pure mathematical problem solving and discovery, provided too little attention to paper-and-pencil calculations, and were not suited for college-level preparation (Wu, 1997).

Despite the fact that conventional textbooks used at the time had little or no evidence of their effectiveness, the release of these new curriculum materials was soon followed by demands for "proof" that they were helping, and not harming, students. Kilpatrick (2003) noted that these demands should not have been surprising:

> Anyone proposing a new school mathematics curriculum faces the task of justifying its adoption. Teachers, parents, and students themselves may be dissatisfied with the current situation, but that does not mean they necessarily welcome change of the sort the new curriculum might demand. Curriculum developers are always in the position of "selling" their product by convincing their potential clients that the change it entails is both manageable and for the better. Research showing improved performance, or at least performance that is no worse than at present, is often used to bolster arguments being made on other grounds. (p. 477)

The fact that the standards-based curriculum materials challenged the status quo by embodying a radically different set of goals for student learning, however, meant that they had a particularly steep hurdle to overcome (Romberg, 1992). Moreover, the demands for "proof" were fueled by intense controversy, embodied by disagreements between two opposing camps (composed primarily, though not entirely, of mathematics educators in one group and university-based mathematicians in the other) that became so strident

that they were dubbed the "math wars" (Schoen, Fey, Hirsch, & Coxford, 1999). As this controversy played out in newspaper editorials, Internet discussions, and articles in popular periodicals, its polarized nature often made it difficult for the general public to distinguish ideology from empirical fact.

In this section, two kinds of studies are reviewed: content-based studies of curriculum materials and evaluations of what and how students learn from curriculum materials. These two kinds of studies share the underlying assumption that curriculum materials—in and of themselves—matter. Although some authors acknowledge the fact that curriculum materials are not self-enacting, these studies do not highlight the enactment process but rather focus on the materials themselves or on the relationship between the adoption of written materials and student outcomes. That is, most studies do not attempt to examine how teachers interpret curriculum materials or how teachers and students interact with the materials in the classroom. Returning to Figure 8.1, the reader might imagine a solid arrow drawn from "Written Curriculum" to "Student Learning" as a way to characterize the studies cited in this section.

Research on Content of Curriculum Materials

The majority of mathematics teachers rely on curriculum materials as their primary tool for teaching mathematics (Grouws, Smith, & Sztajn, 2004). If a topic is not included in their curriculum materials, there is a good chance that teachers will not cover it.[5] And, as noted by Hiebert and Grouws (this volume), one of the best substantiated findings in the literature on classroom teaching and student learning is that students do not learn content to which they are not exposed. Thus, the identification of *what* mathematical topics are covered in a given set of curriculum materials is of fundamental importance.

Others argue, however, that "the mere presence of content in a textbook does not ensure that students will learn that content. For real learning to take place, textbooks must focus sound instructional strategies on the ideas and skills that students are intended to learn" (Project 2061, n.d., part 2). The myriad decisions that curriculum developers make regarding issues such as how material should be presented reflect the developers' theory of how students learn mathematics. These dimensions, which we discuss under the label of *how* content is presented (as opposed to *what* content is presented), are important because they set into motion different pedagogical approaches and different opportunities for student learning.

Finally, some curriculum materials aim to promote teacher learning in addition to student learning. If one believes that students' opportunities to learn are the product of ongoing interactions among the text, the student and the teacher, then what students learn will be influenced by their teachers' understanding of and presentation of the material in the text. Given the plethora of findings about the impoverishing effect that limited content knowledge has on teachers' interpretation and use curriculum materials, especially novel and highly demanding materials such as standards-based curriculum materials (see studies reviewed in Section Four), we argue that a third dimension worthy of investigation is the extent to which the curricular materials are educative (Davis & Krajcik, 2005) for teachers. Each of these approaches to examining students' opportunities to learn—What Content is covered? How is Content Presented? And with what support for teacher learning?—is reviewed below.

What Content is Covered?

Content analysts normally compare selected curriculum materials against a set of external criteria to determine depth and/or breadth of coverage. Analysts in the United States typically use standards, frameworks, or other countries' curricula as their external criteria (NRC, 2004). Over the past decade, the external criteria used by researchers to analyze curriculum materials have varied widely, reflecting the various values held by the individuals who have conducted them.

Not surprisingly, these variations have produced different results. In their review of 36 content analyses, the NRC (2004) found that the ratings of many curricular programs vacillated from strong to weak depending on who had reviewed them and according to what criteria. Differences in values have not and cannot be decided by empirical analyses. However, once one's values are clear and learning goals compatible with those values have been specified, questions regarding what curriculum is most effective (for achieving those goals) can be answered empirically (Hiebert, 1999). As concluded by the NRC panel (2004), curriculum decision makers for schools and districts should select

[5] In recent years, the chances of students not being exposed to a topic if it is not in the curriculum have been somewhat mitigated by state standards. Most districts check their curricula for alignment to state standards. If a topic is found to be in the standards but not in their textbooks, they frequently find supplementary materials to address the gap.

reviews whose underlying dimensions are compatible with their values and learning goals.

It is in this spirit that we report the approaches and findings from three of the most prominent content analyses performed over the past decade: Project 2061 of the American Association for the Advancement of Science (AAAS), the ratings of curricula by the US Department of Education, and the work of Mathematically Correct.

Project 2061. One of the first, systematically documented analyses of the mathematical content of curricula was conducted in the late nineties by the American Association for the Advancement of Science [AAAS]) of middle school (and subsequently of algebra) textbooks. According to their website, the emergence of the NCTM Standards in 1989 along with AAAS's benchmarks for scientific literacy (which were closely aligned with the NCTM Standards) provided—for the first time—a solid, widely acknowledged conceptual basis for evaluating textbooks based on what students should learn. In their evaluation of 13 middle school curricula, they used a "relatively small but carefully chosen set of benchmarks to identify the strengths and weaknesses of the curricula." These benchmarks, they claimed, "deal with concepts and skills that nearly everyone would agree are important for middle school students to achieve." Another important aspect of their methodology was the decision to conduct in-depth examinations of a relatively small—but important—number of topics as opposed to examining more topics in a more superficial manner.[6]

The benchmarks used for their review of middle-school curricula included the following:

> *Number Concepts:* The expression a/b can mean different things: a parts of size 1/b each, a divided by b, or a compared to b.
>
> *Number Skills:* Use, interpret, and compare numbers in several equivalent forms such as integers, fractions, decimals, and percents.
>
> *Geometry Concepts:* Some shapes have special properties: Triangular shapes tend to make structures rigid, and round shapes give the least possible boundary for a given amount of interior area. Shapes can match exactly or have the same shape in different sizes.
>
> *Geometry Skills:* Calculate the circumferences and areas of rectangles, triangles, and circles, and the volumes of rectangular solids.
>
> *Algebra Graph Concepts:* Graphs can show a variety of possible relationships between two variables. As one variable increases uniformly, the other may do one of the following: increase or decrease steadily, increase or decrease faster and faster, get closer and closer to some limiting value, reach some intermediate maximum or minimum, alternately increase and decrease indefinitely, increase or decrease in steps, or do something different from any of these.
>
> *Algebra Equation Concepts:* Symbolic equations can be used to summarize how the quantity of something changes over time or in response to other changes. (Project 2061, n.d., part 1)

Results are presented in a matrix form for each of the 13 curricula that were reviewed. These matrices provide a content rating for each of the above criteria at one of three levels: most content, partial content, and minimal content. Page numbers and sections that provide evidence for meeting each of the content levels are provided.

The results of this review have been summarized as follows:

> Most middle grades textbooks do a credible job addressing number benchmarks. However, only the best ones develop meanings for fractions, for example, by having students measure, build models, use number lines, and compare fractions to acquire a full understanding. Almost all textbooks present the formulas in geometry. But even some of the best ones fail to relate geometry skills to real-life ideas, such as the triangular structures used in bridges or the relationship between the distance around a city park and the area enclosed. . . . Few textbooks do a good job teaching how graphs show relationships, and instead focus on simple, linear graphs. The best series involve students with data collection in situations like a bicycle tour, giving them first-hand experience connecting concepts, such as time and distance, with tables and graphs. With this solid foundation, variables and equations are used naturally and with understanding (Kulm, 1999).

Only four of the thirteen middle-grades curricula—all standards-based—were rated satisfactory; that is, high enough to be confident that students would learn the content of the selected benchmarks. These curricula were, ranked in order, *Connected Mathematics, Mathematics in Context, MathScape,* and *Middle*

[6] This speaks to the criticism of American curricula and programs as being a "mile wide and an inch deep" (Schmidt, McKnight, & Raizen, 1997) by focusing on the identification and treatment of "big ideas," the understanding of which should place students in good stead for future mastery of more advanced mathematical content.

Grades Math Thematics. None of the conventional curricula were rated as satisfactory. These textbooks were judged to be lacking in their coverage of important mathematics, and to provide little development in sophistication from grades 6 to 8. (See Appendix A for ratings of various curricula by the AAAS,'s Project 2061, the Department of Education, and Mathematically Correct.)

U.S. Department of Education. In 1999, the U.S. Department of Education conducted a review of mathematics curricula to identify promising and exemplary curricula. According to the NRC panel (2004), this evaluation was guided by eight criteria structured in the form of questions (page 68):

1. Are the program's learning goals challenging, clear, and appropriate; is its content aligned with its learning goals?
2. Is it accurate and appropriate for the intended audience?
3. Is the instructional design engaging and motivating for the intended student population?
4. Is the system of assessment appropriate and designed to guide teachers' instructional decision making"
5. Can it be successfully implemented, adopted, or adapted in multiple educational settings?
6. Do its learning goals reflect the vision promoted in national standards in mathematics?
7. Does it address important individual and societal needs?
8. Does the program make a measurable difference in student learning?

Although *The Curriculum and Evaluation Standards* of the NCTM are not specifically mentioned, they were used (and assumed to be used) as the national standards referred to in question #6. Not surprisingly, once again, the standards-based curricula fared better under these criteria than did more conventional curricula, with the *Connected Mathematics Project* (CMP), the *Middle School Mathematics through Applications Project* (MMAP), the *Cognitive Tutor, College Preparatory Mathematics* (CPM), *Contemporary Mathematics in Context* (Core-Plus), and the *Interactive Mathematics Program* (IMP) being named exemplary and *Everyday Mathematics, MathLand, Number Power,* and the *University of Chicago School Mathematics Program* (UCSMP) *Integrated Mathematics 7–12* being labeled promising.

Shortly after these evaluations became public, the criteria used by the Department of Education came under attack by opponents of NCTM *Standards* and Standards-based reform. For example, Richard Askey, a professor of mathematics at the University of Wisconsin and one of the authors of an open letter (signed by 200 professional mathematicians) sent to prominent national newspapers and to *Education Week* stated, "Some of the recommended programs are very careless with the mathematical core." Furthermore, he questioned the role of the NCTM *Standards*, saying, "To put in as one of the criteria that curriculum materials should be aligned with the NCTM Standards is inappropriate. We want good mathematics programs, and these do not necessarily have to be based on the NCTM Standards." Other prominent mathematicians defined their concerns with specific features of the "exemplary" curriculum materials, such as their light treatment of standard algorithms and heavy use of calculators (e.g., Klein, 2000).

Mathematically Correct. The organization of concerned mathematics professionals and parents known as Mathematically Correct have provided the third set of noteworthy content reviews in the past decade. Their reviews of second, fifth and seventh-grade mathematics textbooks (both standards-based and conventional textbooks) are guided by the concept of preparing all students for pre-algebra by eighth grade and by various sets of standards. In the seventh grade review (presented here for comparison to the criteria used by AAAS in their review of middle school textbooks), this organization evaluated "a set of key topics, representing an array of algebra readiness concepts, knowledge, skills, and problem-solving applications. Key benchmarks within these areas were drawn from various standards documents and used as the content basis for the review of each mathematical topic" (Mathematically Correct, n.d.a, p.1) The content areas were: Properties, order of operations; Exponents, squares, roots; Fractions; Decimals; Percents; Proportions; Expressions and equations-simplifying and solving; Expressions and equations-writing; graphing; Shapes, objects, angles, similarity, congruence; Area, volume, perimeter, distance.

Under each of these topic areas, detailed specifications were provided regarding what students should learn. Compared to the AAAS criteria for middle school curricula, the Mathematically Correct criteria focus more heavily on mastering procedural manipulations and rules. For example, under the first topic area, " Properties, order of operations" they state:

> At this level students should master the rules of order of operations and the properties of the real number system (commutative, associative, distributive, identity and inverse) and be able to apply them, with justification, with all four operations in calculations involving fractions, decimals, percents, positive and negative numbers, and in the simplification of simple roots and powers. This should include the simplification of numerical expressions, the evaluation of expressions with substitution of numerical values and the solution of simple one and two step algebraic equations (Mathematically Correct, n.d.a, p.2).

The concern of Mathematically Correct is mastery of what they term, the mathematical core, the essential elements of knowledge and skills that students need to succeed in more advanced mathematics. Their criteria for mastering this core include procedural fluency, conceptual understanding and the ability to apply newly learned information to novel situations—criteria that most subscribers to the NCTM Standards would endorse as well. As we shall see in the next section, one of the main differences between NCTM Standards subscribers and Mathematically Correct members can be found in their respective notions of how—and in what order—students should learn the mathematical core.

Under the Mathematically Correct evaluations, conventional textbooks fared better than did standards-based curricula. (Appendix A identifies the curricula that have been rated by Mathematically Correct and the overall "grade" they received.) The highest "grade" received by a standards-based curriculum was a "C" for *Everyday Mathematics*; all others received a "D" or "F." Meanwhile, all but two of the conventional curricula received an "A" or "B" (Mathematically Correct, n.d.b)

In sum, the three content reviews cited in this section make clear the need for transparency regarding the criteria used for content review of curriculum materials. Using very different sets of criteria, AAAS and the US Department of Education reviews produced recommendations that were nearly the opposite of the recommendations produced by reviews conducted by Mathematically Correct. This suggests that consumers and decision makers must first define what *they* value in terms of student learning and then select a review that encompasses their values as closely as possible (Hiebert, 1999).

Another way of framing the issue is in terms of tradeoffs. For example, one feature that distinguishes the AAAS review from the Mathematically Correct review is the extent to which each focused on depth versus breadth. Whereas AAAS examined a few topics in great depth (reflecting their belief that students need to develop multi-faceted, in-depth understanding of a few, salient mathematical topics or ideas), Mathematically Correct's reviews reflected the comprehensive range of skills that they believe students need to succeed in advanced mathematics courses. Each approach can be seen as having both virtues and drawbacks. Being aware of the criteria used in content reviews allows decision makers to surface and articulate this and other tradeoffs (some of which will be illuminated in the next section) and make informed decisions regarding what best fits with their K–12 instructional program, their goals for student learning, and their institutional resources and constraints.

How is Content Presented?

The above analyses primarily focused on *what* is included (and excluded) in various curriculum materials. We turn now to a discussion of *how* that content is presented, that is, analyses that more sharply focus on pedagogical intent. Similar to the analyses of content coverage discussed above, the criteria that researchers have used to make judgments about the pedagogical intent of various curricula are necessarily related to personally held views regarding the nature of mathematics and how students learn it. If one believes that mathematics is best learned through student construction based on active exploration, one set of criteria will be selected to guide one's analyses. On the other hand, if one believes that mathematics is best learned through direct instruction and skills practice, then review criteria will be of a different sort.

A host of curricular features have the potential to influence how teachers use and thus how students experience curriculum materials. These include pretests to assess prior student knowledge, embedded assessments, suggestions for tailoring the material for students at different levels, the inclusion of group work activities, and the encouragement of student discussion of ideas. In this section, we begin with a discussion of several overarching design features that can have potentially far-reaching effects on how students learn mathematics. We then briefly review how two organizations, AAAS and Mathematically Correct rated curriculum materials with respect to how they presented content.

Overarching features of curricula. Most standards-based and conventional curricula intend for students to learn concepts, skills, applications, problem-solving and efficient procedures. They differ, however, with regards to the order and manner in which these elements are presented, the balance that is struck among various elements, and organizational style. Each of these is discussed below.

1. *Order and manner of presentation.* Conventional curricula tend to rely on direct explication of the to-be-learned material as well as careful sequencing and accumulation of lower-level skills before presenting students with the opportunity to engage in higher-order thinking, reasoning and problem solving with those skills. Students typically are expected to master definitions and standard algorithmic procedures *before* they are exposed to opportunities to apply their knowledge. In contrast, standards-based materials rarely explicate the to-be-learned concepts *for* the students; instead they rely on student engagement with well-designed tasks to surface the concepts. Active exploration of the concept-to-be-learned is viewed as allowing students to induce important facets of the concept based on their own reasoning and thinking. After the concept has been surfaced and its features explored by students, the curriculum and teacher step in to apply definitions, standard labels, and (sometimes) standard procedural techniques related to the concept.

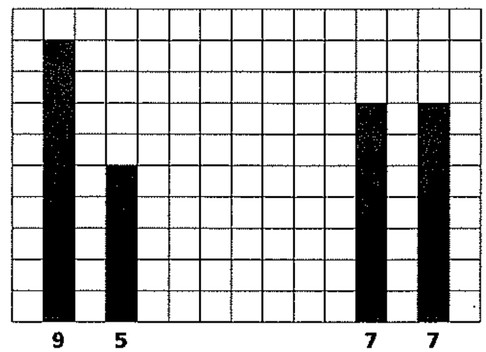
To illustrate the above contrast, consider two ways in which curricula might approach the concept of the mathematical average. Conventional curricula would begin with the provision of an explicit definition of the concept of average (i.e., a measure of central tendency) and would then demonstrate the conventional algorithm for finding the average of a set of numbers (taking the sum of the numbers in the set and dividing the sum by the number of addends). After practicing this procedure on several sets of numbers, students would be asked to apply what they have learned by finding the average in the context of word problems. In contrast, standards-based curricula would not begin with an explicit definition of the concept of average but rather would immerse students in a task that requires that they experience what an average means, for example, as is done with the task shown in Figure 8.2 (found in *Visual Mathematics/Math Alive).*

As students grapple with this task, they would be approaching the concept of average through a frame of "leveling" and thus be encouraged to recognize what an average does, i.e., it evens out the extremes of a given population, a recognition that is important when deciding which measure of central tendency might be the most valid representation of a population given a particular question. Students could also be drawn to recognize that the average can be a number that is not represented in the population, as is the case in this problem. Only after exploring these more qualitative, conceptual features of the mathematical average would students be introduced to the conventional procedure for finding the average.

The theory of knowledge and of how students learn is radically different in these two approaches.

The pairs of numbers in a–d below represent the heights of stacks of cubes to be leveled off. On grid paper, sketch the front views of columns of cubes with these heights before and after they are leveled off. Write a statement under the sketches that explains how your method of leveling off is related to finding the average of the two numbers.

a) 9 and 5 b) 16 and 7 c) 7 and 12 d) 13 and 15



By taking 2 blocks off the first stack and giving them to the second stack, I've made the two stacks the same. So the total # of cubes is now distributed into 2 columns of equal height. And that is what average means.

[Taken from *Visual Mathematics*, (Bennett & Foreman, 1989)]

Figure 8.2 Task used in *Visual Mathematics* to develop students' understanding of the concept of average.

In the more conventional approach, knowledge is viewed as a Gagne-like (1977) hierarchy of skills and learning is viewed as proceeding from lower-level to higher-level skills. Without the prerequisite lower-level skills, this approach argues, students will not be able to master higher-order skills. In the standards-based curricula, on the other hand, learning is viewed as the development of understanding through the construction of increasingly detailed relationships between concepts. In this perspective on learning, students are viewed as making meaning of new information by relating it to their prior knowledge; learning is said to have occurred when students develop an understanding of the relationships between and among concepts and between concepts and procedures (Hiebert et al., 1997).

2. *Balance.* Curriculum materials also differ with respect to the balance that they strike among a number of elements including a) between concepts and procedures, b) between calculator-aided vs unaided computation, and c) among various kinds of representations including numerical data, manipulatives, tables, graphs, and equations. Again, the particular balance that is struck reflects the developers' philosophy regarding how students learn mathematics. For example, in summarizing reviews of algebra curricula, Clopton, McKeown, McKeown, and Clopton from Mathematically Correct (1998) expressed concern re-

garding the impact that calculators have on the development of computational fluency and tended to discourage their use. Many researchers favorable to the NCTM Standards, on the other hand, applaud the introduction and use of calculators, because of their ubiquity in present-day society and their belief that off-loading computational burdens from students "frees up" cognitive space for higher order thinking and reasoning. With regard to the balance between concepts and procedures, not surprisingly, conventional materials tend toward a balance that weighs heavily toward practice on procedures while standards-based curriculum materials are weighted more toward the development of concepts and problem solving.

3. *Organizational style.* Finally, conventional versus standards-based curriculum materials differ in terms of their overall organization. Most conventional textbooks are organized into units and chapters that follow topics that have been identified as appropriate for each of the particular grade levels. Many are also organized as a "spiral," meaning that specific topics are introduced and re-introduced throughout a set of grades with increasing levels of sophistication each time that students encounter them. Students are not expected to master the topic the first time it is introduced, but rather are expected to deepen their understanding and attain eventual mastery over time as the topic is revisited. Stein and Kim (2006) refer to spiral and other tightly sequenced curricula as *integral* curricula. In integral curricula, knowledge and skills are tightly woven into the fabric of the curriculum (i.e., they cannot be easily separated out) and they must be taught in a specified sequence over the years.

Integral curriculum materials can be contrasted with *modular* approaches in which the subcomponents can be separated and even recombined into new and varied configurations with little loss to the overall effectiveness in attaining curricular goals (Stein & Kim, 2006). Many standards-based curriculum materials are modularized with each module designed to represent a big idea or integrating conceptual theme. For example, *Bits and Pieces,* a sixth grade module from *Connected Mathematics,* subtitled "Understanding Rational Numbers" focuses on moving between and among fractions, decimals, and percents. Typically, students complete 6–12 modules per school year.

By and large, research has been silent on the tradeoffs associated with integral versus modular forms of curricular organization. Stein and colleagues (Stein & Kim, 2006) have proposed that integral curricula place more demands on the social cohesion of a school's faculty (which they conceptualize as social capital) because they require that all teachers buy into one curriculum and dutifully carry out their responsibilities with respect to teaching the requisite skills at each grade level. Modular approaches, on the other hand, can afford to be taught by some teachers, but not all. Such approaches can also be used in variable sequences (within a given grade level or sometimes across two consecutive grades). Moreover, because the to-be-learned knowledge and skills are more easily identifiable and viewed as separable from the curricular fabric, modular curriculum materials are more amenable to progressive implementation within a reform effort (i.e., implementing only a partial set of modules for the first year, a few more the second year, and so forth).

In sum, the above discussion of design features illustrates the range of decisions that developers make (either implicitly or explicitly) as they design materials for student consumption. Moreover, the features discussed above—order and manner of presentation, balance, and organizational style—are not features that typically appear on textbook review checklists. Rather they are subtle attributes whose presence becomes felt over time as teachers use the materials and observe their impact on how students and their colleagues engage with the materials. Surfacing these distinctions and their potential implications for how students learn mathematics would be a significant move forward for decision makers in most schools and districts.

Reviews of how content is presented. The reviews conducted by AAAS and Mathematically Correct illustrate the selection of two very different sets of dimensions for judging the pedagogical quality of mathematics curricula. AAAS claims to have based their review of middle school curricula on criteria "derived from research on learning and teaching and on the craft knowledge of experienced teachers" (Project 2061, n.d., part 1, p. 3). Reviewers were trained to rate the extent to which textbooks explicitly included information with respect to 24 instructional criteria ranging from the specification of prerequisite knowledge to the guiding of interpretation and reasoning. The 24 criteria were organized into seven categories (identifying a sense of purpose, building on student ideas about mathematics, engaging students in mathematics, developing mathematical ideas, promoting student thinking about mathematics, assessing student progress in mathematics, and enhancing the mathematics learning environment), each of which was justified by findings from research on learning and teaching.[7] The criteria

[7] Sources that are cited include *Science for All Americans* (AAAS, 1990), *Benchmarks for Science Literacy;* (AAAS, 1993) and the *Handbook of Research on Mathematics Teaching and Learning* (Grouws, 1992).

and organizational categories are also cited as being compatible with NCTM's 1989 Standards.

One example of an organization category will illustrate the view of teaching and learning embodied by the AAAS approach. Category IV, labeled "Developing Mathematical Ideas" is justified as such:

> Mathematics literacy requires that students see the link between concepts and skills, see mathematics itself as logical and useful, and become skillful at using mathematics. Six criteria are used to determine whether the material justifies the importance of benchmark ideas, introduces terms and procedures only as needed, represents ideas accurately, connects benchmark ideas, demonstrates/models procedures and provides practice.

The above rationale cites the need for practice and accuracy, but also stresses the importance of students viewing mathematics as meaningful and useful; moreover, much of the emphasis is on the making of connections and the introduction of terms and procedures *as needed.* As such, the view of teaching and learning appears to be closely aligned with a constructivist, meaning-making approach to mathematics.

AAAS's analysis of instructional strategies revealed stark contrasts among the textbooks with respect to the adequacy of instruction for the specific benchmarks. Four curricula are highly rated for their engagement of students, development of mathematics concepts, and support of teachers, the same four that were rated high for content: *Connected Mathematics, Mathematics in Context, MathScape,* and *Middle Grades Math Thematics.* The remaining curricula (all conventional) were judged to be unsatisfactory with respect to instructional support. They were judged to be particularly unsatisfactory in offering a purpose for learning mathematics, taking account of student ideas, and promoting student thinking.

Mathematically Correct based their reviews of pedagogical worthiness on examination of two main dimensions: "quality of presentation" and "quality of student work." For "quality of presentation," the following were examined: "clarity of objectives within each lesson and within a topic as a whole, clarity of presentation, a sufficient number and appropriate examples, reasonable guided practice or scaffolding of the early stages of implementation of new knowledge, and a general sense that students would have a high probability of mastering the material at the level at which it was taught" (Mathematically Corect, n.d.a, p. 5). For "quality of student work," they examined the following: "Is there enough chance to practice what is taught, is the work well designed, and is the work at an appropriately high level? Importantly, a range depth and scope of student work should be provided, appropriately building from the simpler, less abstract cases to the more difficult ones" (Mathematically Correct, n.d.a, p. 5).

Using these criteria for their review of seventh grade curricula, the Mathematically Correct reviewers gave the two standards-based curricula (*Connected Mathematics* and *Math Thematics*) the lowest scores. According to their website (Mathematically Correct, n.d.c, p. 5), "these books fall notably short in content, have ill-defined goals for each lesson, as least in the eyes of the reviewers, and have insufficient or poorly designed student work." The curricula that we have called conventional fared much better, notably those published by Saxon. Unlike the other conventional curricula which the reviewers found to be compromised by a "fusion" of teacher-directed lessons and activities based on "discovery learning and the constructivist theory of knowledge," (Mathematically Correct, n.d.c, p. 4) the Saxon curricula were found to have clarity of focus, regular practice on important topics, and to be concise enough to discourage teacher variation with regards to decisions regarding coverage.

The reader can begin to get a sense of how these two sets of evaluations privilege different approaches to teaching and learning mathematics. Not surprisingly—as with the content analyses—the same curriculum fares very differently depending on which set of criteria are applied. Again, decisions can be viewed as tradeoffs set against the backdrop of consumers' beliefs and values, combined with an analysis of their institutional resources and constraints. Potential consumers need to pose to themselves and answer questions such as the following: What kinds of knowledge and skills will prepare our students for their most likely futures? Do our students need to become procedurally sharp by building on their successes through repetition and diligent practice? Or is our ultimate goal students who recognize and begin to deal with complexity—students who, nonetheless, may have to deal with frustration along the way because they will not always arrive at a correct solution in a neat and timely manner? Are our teachers up to the task of teaching in more complex ways and/or following an integral curriculum to assure a coordinated instructional program across grade levels? The posing and answering of these questions depends on awareness of one's values, an accurate picture of one's institutional context, and the ability to assess curricula according to criteria that are transparent to consumers.

The Support of Teacher Learning

As noted earlier, the standards-based curricula tend to embed much of the mathematics learning

implicitly within the tasks themselves. Students are viewed as learning mathematics by "doing mathematics" as opposed to having mathematical concepts and procedures explicitly and directly taught to them by the curricular materials (and the teacher). This student-centered approach to the learning of mathematics places considerable demand on teachers who must organize the physical and normative environment to be conducive to student inquiry, scaffold student actions and thinking as they grapple with cognitively challenging tasks, deal with student ideas that are off-track, and, finally, bring closure to a lesson that is rooted in many different student-designed methods of approaching a given task and a variety of levels and kinds of understanding of the to-be-learned concept(s).

Recently, researchers have begun to identify ways in which curricular materials might be designed so as to assist teachers to learn subject matter themselves—a prerequisite for this kind of teaching—as well as to learn how to better assist student learning of subject matter (Ball & Cohen, 1996; Davis & Krajcik, 2005). These features comprise elements that are added on top of the "base curriculum," that part of the curricular materials that is designed for direct student consumption. Educative curricula incorporate elements that are meant specifically for *teacher* learning and are distinguished from typical teacher guides that steer teachers' actions but not their thinking.

This is a relatively new area of research but is becoming increasingly important as student-centered materials gain a foothold in the marketplace and as teachers struggle to learn a new way of teaching mathematics. The most developed framework for judging how well curricula promote teacher learning identifies five high-level guidelines for educative curricula (Davis & Krajcik, 2005, pp. 5–6):

1. Educative curricula could help teachers learn how to anticipate and interpret what learners may think about or do in response to instructional activities.
2. Educative curricula could support teachers' learning of subject matter.
3. Educative curricula could help teachers consider ways to relate units during the year.
4. Educative curricula could make visible curriculum developers' pedagogical judgments.
5. Educative curricula could promote teachers' pedagogical design capacities or their ability to use personal resources and the supports embedded in the materials to adapt curriculum to achieve productive instructional ends (as opposed to performing "lethal mutations") (Brown & Campione, 1996, p. 291).

Building on this work, Stein and Kim (in press) analyzed two standards-based curricula (*Everyday Mathematics* and *Investigations*) in order to assess the extent to which they (a) made visible the curriculum developers' rationales for specific instructional tasks and/or for particular learning pathways advanced in the base curricula; and (b) helped teachers to anticipate how students might approach these tasks. Referring to the visibility of developers' judgments as "transparency," Stein and Kim reasoned that teachers who had a clear idea of where a particular task was headed mathematically would be better equipped to guide the classroom enactment of the task, especially when it did not go as planned. The ability to anticipate student thinking in response to the task, they reasoned, would allow teachers to plan ahead for how they might deal with the diversity of student responses that open-ended tasks often generate. They found differences between the two curricula with *Investigations* offering more rationales regarding the mathematical significance of tasks and more support for teachers to anticipate student thinking. Preliminary evidence regarding the impact of these differences on teacher implementation of these two curricula suggests that the open-ended tasks of *Investigations* can be enacted with considerable fidelity when teachers make use of the teacher support material whereas the relatively more constrained tasks of *Everyday Mathematics*[8] were nonetheless difficult to implement with fidelity when teachers were unsure of the mathematical purpose of the tasks or how students might respond to them (Stein, Kim, & Seeley, 2006).

Brown (in press) distinguishes two different principles that can be used to organize teacher materials: resource-centric and procedure-centric. A resource-centric approach to the design of teacher materials emphasizes the key building blocks of lessons and tries to make visible the pedagogical affordances of the building blocks, but leaves up to the teacher how, when, and whether to implement the various building blocks. A procedure-centric approach, on the other hand, focuses on the actions involved in carrying out the lessons. Stein and Kim (in press) view

[8] The majority of *Investigations* tasks were coded as "doing mathematics" (open-ended, unstructured), whereas the majority of *Everyday Mathematics* tasks were coded as "procedures with connections to underlying concepts and meaning." See Stein et al. (1996) for an explanation of these levels of cognitive demand.

the teacher materials that accompany *Everyday Mathematics* as procedure-centric and the teacher materials that accompany *Investigations* as resource-centric. They stress that how and where to implement each depends on the nature of the base curriculum and the institutional context.

In this sub-section (Research on Content of Curriculum Materials), we have reviewed research that has focused directly on curriculum materials, framing our review in terms of the opportunities for student learning afforded by different curricula. Our basic finding is that students' opportunity to learn is in the eye of the beholder. An examination of Appendix A illustrates what may now seem to be predictable disagreements between Mathemtically Correct and AAAS/Department of Education reviewers (see, for example, the disparate ratings for *Connected Mathematics*). If one adopts the view of teaching and learning espoused by the NCTM standards (that served as a design blueprint for most standards-based curricula) and consults reviews that base their criteria on the NCTM Standards and like-minded sources, one finds that the standards-based curriculum materials are highly rated. On the other hand, if one believes that mathematics is better taught and learned through more explicit, direct instruction and practice of what is taught and consults reviews that build their criteria from sources such as Mathematically Correct, one finds that the standards-based curriculum materials come up considerably short.

A second finding, which is obvious but nevertheless worth noting, is that standards-based and conventional curriculum materials really do appear to provide very different opportunities for student learning. Although the various reviewers used different criteria, they used them consistently suggesting that standards-based curriculum materials provide more opportunities for students to learn how to think and reason and fewer opportunities to learn and practice basic skills. Conventional textbooks, on the other hand, appear to provide more systematic opportunities to learn definitions and practice demonstrated skills but fewer opportunities to learn when and how to apply those skills.

Finally, our review suggests that standards-based curriculum materials differ with respect to the kind of support materials that they provide *for teachers*. We also suggest that this issue is more complex than discovering that one approach (e.g., the resource-centric approach) is more effective than another. Rather, the kind of teacher-support materials that are most helpful will most likely depend on the nature of the base curricula, as well as the experience level and instructional capacities of the teachers who will be implementing the materials. The issue of teacher learning from curriculum materials opens up an entire new set of design considerations that developers must attend to and that researchers must learn to evaluate.

Our examination of curriculum materials with respect to students' *opportunities to* learn represents only the first step—albeit an important first step—to investigating curricula's actual impact on student learning. In the next sub-section, we turn to studies that collected data on what students learned when they were exposed to these curriculum materials in the classroom.

Examination of Student Learning from Mathematics Curriculum Materials

All of the NSF-supported curriculum projects were required to conduct both formative and summative evaluations of their materials (NSF, 1989). Virtually all developers conducted pilot tests of their materials as various units were under construction or in different stages of completion. A key element of these formative assessments was to uncover what students were able to do and understand as a result of their exposure to the curricula's tasks. Developers also conducted summative evaluations, many of which are reported in an edited volume by Senk and Thompson (2003) entitled, *Standards-Based Mathematics Curricula: What Are They? What Do Students Learn?* Some developers also received additional funding once their materials had been completed to conduct additional studies of their impact.

On the whole, the early evaluations of standards-based curricula as reported in the Senk and Thompson volume were promising. After reviewing syntheses of findings for the four elementary curricula, Putnam (2003) stated:

> The first striking thing to note . . . is the overall similarity of their findings. Students in these new curricula generally perform as well as other students on traditional measures of mathematics achievement, including computational skill, and they generally do better on formal and informal assessments of conceptual understanding and ability to use mathematics to solve problems (p. 161).

Similarly, Chappell (2003) notes that, collectively, the evaluation results provided for three middle school curricula provide "converging evidence that standards-based curricula may positively affect middle school students' mathematics achievement, in both conceptual and procedural understanding." (p. 290). And, finally, Swafford (2003) reviewed syntheses of findings across five high school curricula and found that students in the reform programs performed as well as students in traditional programs on tests designed to measure traditional content and that they

outperformed them on tasks designed to measure the content and processes emphasized in their materials (pp. 458, 460). Given the very different goals and approaches of the new standards-based curricula, these initial reports suggesting that students taught with these materials demonstrated at least comparable levels of computational learning as students taught with conventional curricula and superior understanding of concepts and problem solving were greeted with enthusiasm by their proponents.

That said, none of the approaches or methodologies used in the studies reported in the Senk and Thompson volume was without flaws. One of the biggest concerns with the studies reported in this volume was the fact that curriculum designers were the primary researchers on most of the studies which inevitably raises conflict-of-interest issues. On the positive side, however, developers who also conduct research on their curriculum materials are in the position to design assessment tasks that tap the knowledge that students should acquire from exposure to their curriculum due to their deep understanding of the material. For example, Mokros (2003) reports on a developer-designed assessment comprised partially of individual interviews that assessed the quality of explanations and use of representations and tools, prominent learning goals associated with the *Investigations* curriculum. These kinds of assessments should yield better information on the extent to which students have learned from the specific curriculum than will standardized tests.[9]

Overall, however, the curriculum designers did not appear to take full advantage of their "insider knowledge" and design such assessments. In one of the concluding chapters of the Senk and Thompson volume, Kilpatrick (2003) noted that many of the most distinguishing features of the curricula that were studied and reported on in this volume were not assessed in terms of the student learning outcomes that would be expected. Rather, the most common instruments used were standardized tests, items from national and international assessments, and the PSAT or SAT. According to Kilpatrick, it appeared as those these measures were being used "more to reassure parents and the public that the new curricula were not harming students than to assess common learning goals" (p. 479).

Other concerns that have been raised about drawing conclusions based on these early studies as reported in the Senk and Thompson volume include the often limited variability in conditions of the studies. For example, the study of the *Trailblazers* curriculum included primarily teachers who had received professional development from the curriculum developers themselves. Also, in many of the early studies, the materials were not always in their final forms, and, in some cases, the curriculum materials had not been used long enough to establish stable implementations. Finally, issues can be raised about the comparability of the groups to which some of the curricula were compared. This leaves one with limited ability to make strong conclusions based on any one of the above studies, although the number of studies and the diversity of approaches represented in the Senk and Thompson volume might—for some readers—increase confidence in the general patterns that emerged.

The above studies were undertaken during the early phases of the dissemination of standards-based curricula. As such, the studies reported in the Senk and Thompson volume might be best understood as "proof of concept" studies, indicating that the standards-based curricula "are working in classrooms in ways their designers intended for them to work" (Kilpatrick, 2003, p. 472). It should also be noted, however, that these studies did not satisfy skeptics who demanded that independent researchers develop more rigorous methodologies with which to examine student learning, a discussion to which we now turn.

Comparative Studies Conducted by External Researchers

Although it may seem simple to evaluate whether or not a new curriculum is better, worse or no different from existing approaches, designing a study to do so is fraught with pitfalls and complications, leading an NRC panel convened to examine evaluations of mathematics curricula to conclude that "comparative evaluation study is an evolving methodology" (2004, p. 96). To start, credible outcomes measures must be identified or created. This can be particularly problematic with standards-based curricula that focus on conceptual understanding, thinking, reasoning, and problem solving—outcomes for which the field has limited measures. Two accessible measures that assess conceptual understanding, reasoning and problem solving, the New Standards Reference Exam and Balanced Assessment, have not been widely used (Schoenfeld, 2006). Many researchers use their own measures whose psychometric properties have not been established (Kilpatrick, 2003).

[9] On the other hand, a limitation of most of the items that were developed to measure student learning by curricular developers is that their psychometric properties were not reported, that is, no reliabilities were reported and often curricular validity was the only type established.

Another challenge involves coming to grips with the issue of the differing goals of standards-based vs. conventional curricula. As noted earlier, both would agree to the need for developing some conceptual understanding and some procedural competence; however, the emphasis placed on each varies dramatically between the two kinds of curricula, as does the amount of emphasis placed on reasoning, problem solving, and communication. In addition, there are differences in the topics covered, with, for example, elementary standards-based curricula covering topics not typically found in conventional textbooks including geometry, statistics, and algebraic reasoning. In a curricular evaluation, the question thus becomes: Does one assess only the goals and topics that the two kinds of curricula have in common or does one assess all students on all goals and topics, regardless of which curriculum they were exposed to?

Third, despite being at the heart of this methodology, the creation of comparison groups can be surpisingly difficult. For example, comparison groups are most often selected based on comparability of student samples. Despite the fact that the comparability of teachers is often not considered, experience suggests that teachers in experimental vs. control groups often differ in their levels of enthusiasm, recent professional development experiences, and in their ability to attract a certain kind of student. The NRC report (2004) raises another common concern: studies that compare classrooms using standards-based curriculum with classrooms whose instruction represents a potpourri of instructional styles and approaches. Even if the two sets of classrooms (i.e., the experimental and control groups) are comparable on student background characteristics, the cleaner, more deliberate instructional approach represented by the standards-based classrooms almost always "wins."

A final issue is determining how the curriculum materials were enacted in the classroom. One cannot say that a curriculum is or is not associated with a learning outcome unless one can be reasonably certain that it was implemented as intended by the curriculum developers. Moreover, there is ample evidence that teachers vary in how they implement the same curricular task (Stein et al., 1996; Tarr, Chávez, Reys, & Reys, in press). Assessing implementation quality using observational methods is extremely resource intensive, especially in large-scale studies, and credible self-report of implementation on survey measures is notoriously difficult to achieve (Ball & Rowan, 2004). Nevertheless, claims about the effectiveness of one curriculum over another are commonly made citing student achievement data, but providing little or no data on degree of implementation.

Given the limitations associated with comparative studies, the question naturally arises: What claims can be made about the impact on student learning of various curricula? This question sits at the heart of the charge given to the NRC panel and their conclusion was:

> . . . the corpus of evaluation studies as a whole across the 19 programs studied does not permit one to determine the effectiveness of individual programs with a high degree of certainty, due to the restricted number of studies for any particular curriculum, limitations in the array of methods used, and the uneven quality of the studies (2004, p. 3).

The report goes on to caution that the inconclusive finding of the panel should not be interpreted to mean that these curricula are ineffective either, but rather that problems with the data and/or study designs prevented the panel from making confident judgments about their effectiveness. (The curricula marked with an asterisk in Table 8.1 were included in the NRC review).

Incontrovertible evidence of curricular effectiveness can be provided only by studies that randomly assign students to standards-based vs. conventional curricula, the so-called "gold standard" of the randomized controlled trail (Mosteller & Boruch, 2002; National Research Council, 2002). Although the NRC panel identified no randomized controlled designs for the 19 programs that they studied, the What Works Clearinghouse (http://www.whatworks.ed.gov/PDF/Topic/math_topic_report.html) has produced a Topic Report on middle school curriculum-based interventions that identifies four randomized controlled studies. Two of these studies yielded significant effects: a study by Morgan and Ritter (2002) that examined the effectiveness of the *Cognitive Tutor Algebra 1* and a study by Kirby (2004) on the effectiveness of *I CAN Learn*. Both curricula are standards-based and computer-mediated. The study by Kirby (2004) consisted of one teacher who taught both *I CAN Learn* and a conventional curriculum and used the Georgia Criterion-Referenced Competency Test, a state test, as the outcome measure. The study by Morgan and Ritter (2002) involved nearly 400 students and 18 teachers across five schools and used the Educational Testing Service's (ETS) Algebra I End-of-Course Assessment as the primary outcome measure. In both studies, students who used the standards-based curriculum outperformed the comparison group that was taught with a conventional curriculum (McDougal Littell's *Heath Algebra* in the case of the *Cognitive Tutor* and an unspecified "traditional" curriculum in the case of *I CAN Learn*). The other two randomized controlled studies cited by the

WWC failed to find significant differences in student learning favoring either the standards-based (the *Expert Mathematician/ UCSMP*) or conventional curricula (*Transition Math* or *Saxon*).

Turning to studies that do not meet the gold standard of the randomized controlled trail, one finds less-certain evidence for any one specific curriculum, but, nevertheless interesting patterns across findings from several large-scale studies that compared achievement in classrooms using a variety of standards-based curricula to achievement in classrooms using conventional curricula. Despite the differences in grades and curriculum studied, and the methodologies employed, many of these studies have produced fairly consistent findings. The first is that students taught using standards-based curriculum, compared with those taught using conventional curriculum, generally exhibited greater conceptual understanding and performed at higher levels with respect to problem solving (e.g., Boaler, 1997; Huntley, Rasmussen, Villarubi, Sangtong, & Fey, 2000; Thompson & Senk, 2001). Second, these gains did not appear to come at the expense of those aspects of mathematics measured on more traditional standardized tests. Compared with students taught using conventional curricula, students who were taught using standards-based curricula generally performed at approximately the same level on standardized tests that assess mathematical skills and procedures (e.g., Riordan & Noyce, 2001; Thompson & Senk, 2001). The differences that occurred were usually not significant, and some show the "standards-based curriculum" students doing slightly better, while others show the "conventional curriculum" students doing slightly better. For example, students in the Core Plus Mathematics Project (CPMP) (a standards-based curriculum) outperformed others on tests of algebraic concepts set in real world contexts, but the students taught using more traditional texts outperformed those in CPMP on tests of algebraic skills set in questions without contexts that did not allow calculators (Huntley et al., 2000). Unsurprisingly, students tend to do well on tests that match the approaches through which they have learned.

It is striking to note the similarity between the patterns of findings reported in the Senk and Thompson volume and the findings of the larger-scale comparative studies conducted by external reviewers. In both cases, students taught using standards-based curricula tended to hold their own on tests of computational skills and to outperform students taught with conventional curricula on tests of thinking, reasoning, and conceptual understanding. This pattern of findings—not the findings of any one study—has prompted some to point to the overall efficacy of standards based curricula (e.g., Schoenfeld, 2002).

But, efficacy for what? It is important to note that students tended to perform best on tests that aligned with the approaches by which they had learned, repeating the well-worn finding that students learn what they are taught. Combined with the findings from the analyses of curriculum materials cited earlier, the research examined here suggests that students taught using conventional curricula will learn to compute better, but not to think and reason better than students taught using standards-based curricula. Students taught using standards-based curricula, on the other hand, will learn to think and reason better and (maybe) to compute as well as their counterparts.

Finally, readers must look beyond sound-bite findings in order to ascertain the level of learning actually achieved by students—both in conventional and standards-based interventions. For example, what does it mean to perform "as well as" one's counterparts? In some studies cited above that meant scoring in the lower percentiles of mathematics achievement (e.g., see Morgan & Ritter, 2002; Kirby, 2004). And, studies finding "no difference" do not always mean that students performed dismally. For example, the What Works Clearinghouse reported "no effect" for a standards-based program (the Expert Mathematician) because there were no significant student achievement differences between students exposed to it vs. a more conventional curriculum. Nevertheless, students made learning gains in both groups (Viadero, 2004 as reported by Schoenfeld, 2006).

The above discussion harkens back, once again, to values. Should schools and teachers primarily be held accountable for developing students' capacities for basic proficiencies or for the development of students' abilities to think, reason and problem solve? If both, how should the two be combined?

Methodologically, we acknowledge the superior power of randomized controlled studies to determine the effectiveness of one curriculum over another and we join the National Research Council in calling for more experimental studies. At the same time, we feel that it is important to acknowledge the questions that randomized controlled studies cannot answer and to make a plea for other kinds of studies as well. Returning to the framework depicted in Figure 8.1, the majority of the comparative studies cited above did not collect data on how the various curricula were enacted in the classroom (the third box in our framework—see Figure 8.1); none examined the way in which teachers engaged with the materials to create the intended curriculum (the second box in our framework). When implementation measures

are included, the findings can become less clear. For example, Boaler and Staples (in press) studied algebra classes across three high schools, approximately half of which used conventional methods, and half of which used standards-based methods. In tests of algebra at the end of their first year of high school, students in the two groups performed at the same level, both in terms of skills and conceptual understanding. However, this was not an indication that the curricular approach did not matter, only that there was a need to look beyond curriculum to the ways in which teachers implemented them. Indeed the most significant factor in comparisons of algebra achievement in this study was the teacher, with large variations between classes *within* the same curriculum. The importance of individual teachers and their particular teaching decisions was also reported by Huntley et al. (2000) who found that different classes in the same curriculum varied to a large degree in classroom implementation and student achievement. And, finally, using multiple, non-observational measures of curricular implementation,[10] Balfanz, Mac Iver, and Byrnes (2006) found differences in levels of curriculum implementation that were associated with differences in student achievement with classrooms that exhibited higher levels of implementation averaging higher achievement gains.

As noted earlier, many scholars and policymakers have (implicitly) conceptualized the question behind student-outcome studies as the testing of a (causal) relationship between curricular materials (the written curriculum—see first box of Figure 8.1) and student learning (the final triangle in Figure 8.1). Our framework, together with findings associated with most of the above studies, suggests, however, that such a conceptualization—although useful for some reasons—is incomplete. Although the above studies that focused on student outcomes can reveal *whether* a particular curriculum achieved superior outcomes, they cannot shed light on *how*. However, knowledge of how an effect was achieved is crucial, both for enhancing the field's understanding of teaching and learning mathematics as well as for others who wish to implement the curriculum and for designers hoping to improve the curriculum. Thus, a review of *only* these studies is insufficient. Without accompanying knowledge of how the various curricula were implemented, students' opportunities to learn remain shrouded. In the best case, this limits our understanding of how desirable effects were achieved; in the worst case, it raises questions about the extent to which the achieved effects on student learning can be attributed to a particular curriculum. Thus, we call for studies that are designed to include both large-scale tests of curricular effectiveness and smaller, but embedded, observational studies of instructional practice.

There are too few studies of this kind, two notable exceptions not withstanding. Tarr, Reys, et al. (in press) compared classrooms that used either standards-based or conventional curricula, collecting both achievement data and observational data on the extent to which the classrooms exhibited a "standards-based learning environment (SBLE)." These observations documented the extent to which teachers created learning environments consistent with the tenets of the NCTM Standards and were not tied to any particular curriculum. They found that students in the classrooms using standards-based curricula that also had high levels of SBLE implementation outperformed students who were in classrooms using standards-based curricula but having lower levels of SBLE implementation. In the aforementioned longitudinal study of three California high schools, Boaler and Staples (in press) utilized a range of qualitative and quantitative methods including student assessments, interviews, and questionnaires, and over 600 hours of classroom observations. As such, they were able to report not only that students in Railside high school (where instruction was built around standards-based curricula) achieved at higher levels,[11] but also the ways that the teachers brought this about through their responses to student thinking, their questioning, and the allocation of time. More studies like this—that attend to both student learning outcomes and the classroom-based mechanisms that appear to relate to those outcomes—are needed.

Despite few studies that examine student learning and instructional practice together, there are many research studies that have investigated the mechanisms and processes by which teachers engage curricula, both in their planning and during instruction. These studies provide an important complement to comparative studies that primarily focus on student outcomes. This brings us to the second area of research that will be reviewed: what happens when teachers engage with and interpret curriculum materials.

[10] The intervention consisted of the University of Chicago School Mathematics Program middle school curriculum supported by professional development, coaching and a surrounding whole-school reform program.

[11] The Railside students achieved at higher levels on all measures (researcher-designed and district examinations) except the standardized test used by the state of California.

SECTION TWO: HOW TEACHERS ENGAGE WITH AND INTERPRET CURRICULAR MATERIALS

This section examines teachers' use of curriculum materials as a factor in student learning from curriculum. As our framework suggests, teachers have a substantial role in interpreting and using written curriculum materials and enacting them in the classroom. In this section, we focus on the first step in this process that is labeled in our framework as the relationship between the written curriculum and the intended curriculum.

As discussed earlier, the written or formal curriculum refers to the curriculum represented in curriculum materials or other teaching resources. The intended curriculum refers to the teacher's intentions, that is, the curriculum the teacher plans to enact. As our model suggests, the intended curriculum is often a derivative of the written curriculum; however, there are distinct differences between the two. On a conceptual level, written and intended curricula are different kinds of representations of curriculum. The former is a set of written guidelines and resources aimed at leading and supporting teachers to enact what curriculum developers imagine taking place in the classroom. The latter is comprised of a set of ideas and plans held in the teacher's head. In this sense, the intended curriculum is more closely aligned with an image of classroom practice than the written curriculum.

A second distinction between the two is that the intended curriculum represents the written curriculum as transformed by the teacher. In other words, the process of reading and using curriculum materials necessarily involves interpretation and meaning making on the part of the teacher. In this way teachers do not merely read and follow written curriculum. Just as reading itself is a process of interpretation (Mailloux, 1982), teachers draw on their own experiences and knowledge to make meaning of what they read in curriculum guides. In this sense, they transform the written curriculum from generic, written description and guidelines to both an image of classroom practice and something that has specific meaning to them.

Scholarly interest in this transformation process and the factors that influence it is motivated, in part, by questions about the extent to which curriculum materials can influence teachers and, subsequently, impact students. Research that examines teachers' use of curricula assumes that teachers play a mediating role in how materials influence student learning and seeks to provide clarity about a) the processes by which teachers use, interpret, and transform curricula, b) the factors that influence it, and c) how conditions and contexts can impact these processes.[12] In this section, we explore how researchers have framed and studied the relationship between the written and intended curriculum and the stances toward conceptualizing the teacher-curriculum relationship represented in the literature. The factors and conditions that influence how teachers engage with curricular materials (b and c above) are explored in Section Four.

Framing of the Relationship between Written and Intended Curriculum

The framework guiding this chapter assumes that written and intended curriculum differ in significant, although sometimes, subtle ways. This view, however, has not always been embraced by curricular scholars. Historical studies of school curricula, for instance, relied heavily on textbooks of the period to reconstruct the contents of classroom practice (Love & Pimm, 1996; Walker, 1976). By highlighting ways that teachers adapted or resisted unfamiliar curriculum programs developed during the period of curriculum reform in the late 1950s and 1960s, researchers such as Sarason (1982), Stake and Easley (1978), and Berman and McLaughlin (1973, 1978) challenged conventional assumptions that teachers merely followed their textbooks and that texts alone represented classroom instruction. These studies frame teachers as active users of curriculum, rather than conduits of it and opened the door to questions about the various ways that teachers make use of curriculum materials in shaping the curriculum they intend to teach. The following discussion examines the variety of ways researchers have described and categorized teachers' approaches to curriculum use.

Content Coverage

As part of a year-long study of how content is determined in fourth grade classrooms, Freeman, Belli, Porter, Floden, Schmidt, and Schwille (1983) undertook case studies of seven teachers using mathematics textbooks published in the 1970s. Their analysis produced what the authors identified as four styles of textbook use that focus on the mathematical content

[12] There are only a handful of studies that examine the processes by which teachers interpret curriculum exclusively; typically, such research is incorporated into studies of how the curriculum is enacted in the classroom. As a resulty, some of the studies cited in this section are also cited in Section Three.

covered. They used the term *textbook bound* to refer to an approach to textbook use in which the teacher followed the guide lesson by lesson, beginning at the first chapter and, more than likely, not completing the last few chapters before the close of the academic year. The *selective omission* style, was similar to textbook bound, however, the teacher skipped some chapters entirely. Teachers who were identified as *basics focused,* placed priority on teaching the four operations and used their textbook selectively to assist them in doing so. Freeman and colleagues also identified a subcategory of these teachers who included the topics of measurement as a basic skill. The final style of use, identified as *management by objectives,* involved following a set of objectives imposed by district and school policy and using the textbooks as tools to attend to the goals set out by these policies.

It is likely evident to most readers that the categories proposed by Freeman et al. (1983) reflect the conventional mathematics curricula that dominated the educational scene at the time. However, what stands out about the approach of these researchers is their focus on content coverage over pedagogical strategies or other dimensions of textbook use.

In their examination of 39 middle school teachers' use of both standards-based and conventional textbooks, Tarr, Reys, et al. (2006) also focused on mathematical content coverage. These researchers were interested in determining how closely teachers followed the content offered in their mathematics curriculum materials, particularly in terms of the distribution of mathematical topics. By comparing the proportion of each program devoted to number and operations, algebra, geometry and measurement, and data analysis and probability to the proportion of lessons taught devoted to each topic, they found that all teachers made both omissions and additions to the material found in the text in favor of number and operations. Lessons on data analysis and probability were omitted most frequently.

Components of the Curriculum

Other ways of categorizing curriculum material use place primary emphasis on differences in *how* teachers use the same lesson. Remillard and Bryans (2004), for example, studied 8 elementary teachers during the first two years of using *Investigations,* a standards-based curriculum program. In their analysis, which drew on interviews and observations, they characterized teachers with respect to the extent to and thoroughness with which they used the structure of the curriculum, its mathematical content, and the pedagogical suggestions and information offered. The two teachers who used the curriculum *narrowly and intermittently* relied primarily on their own teaching routines and other resources to guide their curriculum choices over the year. When they did use the standards-based curriculum program adopted in their school, they tended to use it by selecting tasks that seemed familiar and using the repertoires they had developed over years of teaching when enacting them in the classroom. The two teachers identified as *adopting and adapting* the curriculum used the materials as a guide for the general structure and content of their mathematics curriculum. They regularly adopted mathematical tasks from the curriculum guides, but drew on their own strategies and approaches to enact them in the classroom, adapting them to fit their familiar approaches to teaching. The authors identified four of the eight teachers as *thorough piloting* the curriculum. These teachers used the materials as their primary guide in teaching mathematics, which included structuring the curriculum, selecting tasks, and facilitating students' work on those tasks. They tended to read and use all parts of the curriculum guides and sought to follow the lessons as suggested.

An important distinction made in Remillard and Bryans' (2004) categorization system is between teachers who read and follow pedagogical guidance offered by the curriculum and those who relied on their own repertoires when using tasks provided by the curriculum. In other words, the same tasks can be used differently by different teachers. Moreover, because the most recent generation of curriculum materials places substantial emphasis on pedagogical practices, considering how and whether teachers use pedagogical information in the materials is critical to understanding the relationship between the written and intended curriculum.

In his study of middle school science teachers using a standards-based science curriculum, Brown (2002) also focused on *how* teachers used the curriculum guide, emphasizing the shifting nature of this relationship. He identified three different ways that teachers used the materials—offloading, adapting, or improvising. *Offloading* refers to when teachers offload curriculum design responsibilities onto the curriculum and follow it fully. *Adapting* refers to when teachers use suggestions offered in the materials but adapt them to suit their particular needs or preferences. *Improvising* refers to when teachers move away from the curriculum suggestions substantially and design their own.

These types of curriculum use are similar to those offered by Remillard and Bryans (2004) in that they focus on the extent to which the teacher used the

guidance offered by the authors. Brown, however, suggests that teachers tend to engage in different kinds of use at different times. The same teacher might offload in one instance, allowing the curriculum to carry the weight of curriculum design. In another instance, she might improvise, drawing on the curriculum minimally. Although his study was of middle school science teachers, Brown's finding that teachers' approach to curriculum use can vary from lesson to lesson depending on a number of factors contributes to what is understood about the relationships between the written and intended curriculum.

Program Philosophy

Lambdin and Preston (1995) studied middle school teachers using *Connected Mathematics* (CMP), a standards-based curricula. Using interviews and observations, these researchers developed three classifications of teachers to represent the patterns they observed across teachers studied. These classifications highlight the teacher's stance in relation to the underlying philosophy of the program. *Frustrated methodologists,* for example, were teachers whose established classroom routines were in conflict with the goals of the curriculum and were reluctant to change. These teachers' use of the curriculum was mechanical in nature and "characterized by disjointed often superficial use of curriculum materials" (p. 135). The frustrated methodologists described by Lambdin and Preston were often torn between two philosophies of teaching, theirs and that underlying the curriculum. The *teacher on the grow,* describes a group of teachers "open to change and anxious to learn" (p. 136) in order to use the new curriculum more successfully. These teachers often experienced initial reluctance or doubt about the intent of the new curriculum, but, overtime, developed appreciation for its intent and approach. Lambdin and Preston described the final group of teachers as *standards bearers.* These teachers had established classroom routines and pedagogical approaches closely aligned with the philosophy of the program.

Lambdin and Preston's (1995) categories for teachers in relation to curriculum materials focus on the degree of match between the teacher's philosophy of teaching mathematics and the pedagogical stance represented in the curriculum. These researchers found that confidence in one's mathematical knowledge was critical in determining how teachers were classified. Of equal importance, however, was their understanding of the program's epistemological stance or philosophy. In fact, they found more evidence of teachers increasing mathematical knowledge and gaining confidence in their knowledge through use of the curriculum than they found of teachers coming to understand and appreciate new pedagogical approaches.

Looking across these differing schemes for categorizing how teachers use curriculum materials, we see significant interest in and reason for identifying and examining the relationship between the curriculum as written and as intended by the teacher. Indeed, there is overwhelming evidence that teachers use and enact curriculum in substantially different ways. The varieties of kinds of use examined hint at the complexity of the relationship between written curriculum materials and teachers' uses of them. Moreover, these varied categorization schemes represent some of the possible ways that curriculum use can differ (e.g., in content coverage, in extent and nature of reliance on various curriculum components, in epistemological and philosophical stance). An examination of the kinds of use identified in these studies as a set can offer insight into the dimensions along which curriculum use can vary. As a field, we ought to take as much interest in these dimensions as we do in the variations within each study. Considering these dimensions as a set can shed light on the complexity of curriculum use. While most studies tend to focus on a single dimension, such as philosophical stance, attending to a set of them can offer a fuller understanding of what matters in teachers' curriculum use. Further, attending to these dimensions raises questions for further research. Are there other dimensions along which variation in use occurs that matter? What are the differential consequences of these kinds of variation for classroom activity? Do some variations matter more than others?

A second reason to examine the dimensions of variation in material use identified by researchers is to uncover points of convergence across studies. The different foci taken by researchers along with the introduction of new categorical schemes and terms to label kinds of use points to a need for clarity in how curriculum use is examined and identified. Given the reality that the predominant methods for studying curriculum use involve intensive observation over extended time frames, it is critical that the field establishes structures that enable aggregation of findings across studies.

A final point to consider when examining studies of curriculum material use by teachers is the extent to which the dimensions of use identified parallel the dimensions used to frame analyses of the curriculum materials themselves. The studies above that examined content coverage by teachers (e.g., Freeman et al., 1983, and Tarr, Chavez et al., in pres) can, to some extent, be viewed as mirroring analyses of curriculum materials that focus primarily on content and topic coverage (see pages 327–330 in this chapter). On the other hand, the research cited above by Remillard and

Bryans (2004), Brown (2002), and Lambdin and Preston (1995) that focused on teachers' use of pedagogical and philosophical dimensions of curriculum materials align with studies of curriculum materials that focus on how the content is presented, both to students and teachers (see pages 330–335 in this chapter). We believe that the knowledge base associated with how curriculum impacts student learning would be advanced if the field established common structures for examining both the materials themselves and the dimensions along which researchers examine teachers' use of those materials.

We now turn to different conceptualizations of curriculum use in the literature and how these stances shed light on the manner in which teachers interact with curriculum materials in shaping the intended curriculum.

Conceptualizations of Curriculum Use

In an analysis of the literature on teachers' use of mathematics curriculum materials Remillard (2005) identified several different ways curriculum use was studied in the literature; three of these approaches represent differing stances on what it means to use curriculum. As a result, they reveal different dimensions of the relationship between the written and intended or enacted curriculum. These three stances on curriculum use include: use as following or subverting, use as interpretation, and use as participating with. The following descriptions are accompanied by illustrative examples from the literature.

Curriculum Use as Following or Subverting

Studies that frame curriculum use as following or subverting view the written curriculum as embodying discernible and complete images of practice and examine the degree to which teachers follow these guidelines with fidelity. These studies implicitly contend that the degree of match between the written curriculum materials and enacted curriculum is measurable. As a result, researchers undertaking such studies concern themselves with how curriculum writers and others might achieve greater clarity and closer guidance for the teacher. These studies that seek to capture "treatment integrity," as called for by the NRC (2004) report, are critical to assessing the impact of curriculum materials on student learning.

This perspective is evident in studies of teachers using conventional curricula as well as in studies of teachers using standards-based curricula. In these studies, researchers found many more cases of subverting the curriculum than of close following. As a result, they tended to make recommendations that might result in greater fidelity, such as increased specificity within curriculum materials and enhanced professional development. It is worth noting that in almost all cases, researchers found that teachers' deviations from the written curriculum reflected tendencies toward conventional pedagogical approaches and representations of mathematics.

Studies by Freeman et al. (1983), Freeman and Porter (1989), Stodolsky (1989), and Sosniak and Stodolsky (1993) all provide examples of analyses of teachers' use of conventional curricula. Their findings revealed that teachers used texts selectively, focusing on basic skills instruction and core mathematical topics, and demonstrated, in Freeman and Porter's words, that the conviction that textbooks determined the mathematics curriculum reflected "a narrow view of teacher decision making" (p. 404).

Studies of teachers using innovative curriculum materials since the 1980s (e.g., Donovan, 1983; Manouchehri & Goodman, 1998; Stephens, 1982; Tarr, Chavez, et al., in press) examined teachers using curriculum materials that reflect unfamiliar views of mathematics and approaches to mathematics teaching. These researchers all found that teachers tended to use mathematical topics and tasks from the curriculum guides, but made alterations as well, often subverting the designers' intentions, transforming the tasks to fit conventional approaches to teaching and classroom management structures.

In a study of 39 teachers from six different states, 17 using standards-based and 22 using commercially produced texts, Tarr, Reys et al. (in press) examined textbook fidelity and its relationship to student outcomes. They measured fidelity by considering: (a) the extent to which the teacher covered topics and lessons in the textbook, (b) the amount of time spent on topics in the textbook, (c) in the case of standards-based curriculum, the extent to which the classroom activities reflected a "standards-based learning environment." They found that, on average, teachers used 60 to 70% of the lessons in the curriculum guides, regardless of the type of curriculum. In fact, the greatest influence on whether lessons were omitted was their topic. Teachers of both kinds of curriculum materials were more likely to omit lessons on data and probability than on number and operations. While the use of standards-based curriculum materials was not a predictor of the presence of a standards-based learning environment (SBLE), measured on a ten point scale, only one classrooms using commercially generated curriculum materials had a SBLE rating over 5. Half of the classrooms using standards-based curriculum materials were rated between 6 and 10 on the SBLE scale.

As a group, studies that examine the closeness of match between a written curriculum and actual practice shed light on the aspects of materials teachers tended to follow as well as the variety of ways they adapt and subvert suggestions in these materials. While teachers are likely to follow the mathematical topics offered in curriculum materials, they do so differentially, favoring topics such as number and operations over probability and statistics. Moreover, they are much less likely to follow the pedagogical recommendations or embrace the philosophical stance of the materials.

Curriculum Use as Interpretation

Research grounded in a view of curriculum use as interpretation assumes that fidelity between written plans in a teacher's guide and classroom action is impossible (Remillard, 2005). This view holds that teachers bring their own beliefs and experiences to their encounters with curriculum to create their own meanings, and that by using curriculum materials teachers interpret the intentions of the authors. In her book on teachers' encounters with curriculum materials, Ben-Peretz (1990) argues that teachers draw on personal knowledge and experience to "assign meaning to the curriculum materials they use daily in their classrooms" (p. 71). Research from this point of view investigates the nature of teachers' interpretations, the factors that influence them, and the resulting classroom practices.

Researchers who view curriculum use as a process of interpretation have applied this view to a range of initiatives intended to influence teaching, including educational policy. In their studies of the relationships among state-level policy, district and classroom practices, researchers with the Educational Policy and Practice Study (EPPS)[13] maintained that policy and its multiple instantiations, such as textbooks and tests, are open to interpretation. Beginning in 1988, EPPS used case-study methods to consider how elementary teachers in California learned about, understood, and acted on state-level mathematics policy in the late 1980s. The state's initial efforts to alter mathematics instruction placed heavy emphasis on approved textbooks to communicate its message of reform. Hence, how teachers interpreted and used their new textbooks was central to this work (e.g., Ball, 1990; Cohen, 1990; Heaton, 1992; Putnam, 1992; Remillard, 1992; Weimers-Jennings, 1990; S. M. Wilson, 1990).

A particularly striking finding from this research with respect to the interpretation of policy and curriculum materials was the conviction with which all of the participating teachers believed that their teaching reflected the ideas of the new policy's reform intentions as a result of their faithful use of a particular textbook or curriculum program. However, their interpretations of the goals of the reform initiative and their uses of their texts varied tremendously. Variations included subtle and not so subtle adaptations of the plans suggested in the text as well as diverging interpretations of what it means to engage students in problem solving or discuss their solution strategies.

A number of researchers studying teachers using standards-based curriculum materials have focused their analyses on teachers' interpretations of the unfamiliar curricula as well as the NCTM *Standards* themselves. Collopy (2003) studied two teachers using the *Investigations* curriculum for the elementary grades and found significant differences in their uses. The most extreme case of this kind of variation was in how the teachers used the illustrative dialogues provided in the curriculum. These scripted conversations, presented in the teacher's guide like the dialogue in a play, illustrated an example of a discussion a class might have about a focal concept or phenomenon. One teacher read them in order to anticipate the ideas that might come up during a class discussion while the other teacher used them as scripts and had students read the different student parts aloud. Collopy attributed these dissimilar interpretations to the teachers' contrasting views of curriculum and the degree to which they had firmly established pedagogical repertoires and curriculum structures.

Like those that frame curriculum use as following or subverting, these studies also highlight variations in how teachers use curriculum resources. They also go a step further in illuminating the process by which these variations occur. By framing curriculum use as an interpretive process, researchers make visible the ways that teachers' meaning making processes shape the intended curriculum. The factors that influence teachers meaning making are discussed in Section Four of the chapter.

Curriculum Use as Participating With

A third perspective taken by researchers studying teachers and curriculum materials focuses on the teacher-text relationship or the activity of using the text. This perspective treats curriculum material use

[13] This group began its work in 1988 on a study of the relationship between state-level mathematics policy and classroom practice in California. Later, in 1992, as it expanded its focus to include three states and policy in two subjects (mathematics and reading), the group took the title EPPS.

as collaboration with the materials (Remillard, 2005). Central to this perspective is the assumption that teachers and curriculum materials are engaged in a dynamic interrelationship that involves participation on the parts of both the teacher and the text. While there is significant overlap between this perspective and the stance that focuses on use as interpretation, the core difference is the focus of the analyses. Indeed, researchers in either category might view curriculum use as a process of interpretation. However, the research in this group seeks to study and explain the nature of the participatory relationship. In other words, the distinguishing characteristic of this perspective is its focus on the activity of using or participating with the curriculum resource and on the dynamic relationship between the teacher and curriculum. Studies taking this perspective consider the ways that particular features of the curriculum resource, as well as the teacher's interpretations of them, work together to shape the intended curriculum.

The view that curriculum material use involves a dynamic interchange between teacher and curriculum is reflected in Lloyd's (1999) study of two high school teachers using *CORE Plus*, a standards-based curriculum. The study investigated "how and why two teachers encountered particular successes and difficulties as each implemented a set of novel curriculum materials for the first time" (p. 229). The author examined the teachers' conception of the curriculum and of key ideas central to it, including exploration and cooperation, and the teachers' resulting mathematics teaching. She argued that "curriculum implementation consists of a dynamic relation between teachers and particular curricular features" (p. 244), but also suggested that this relationship can be strained by tensions between the structure outlined in the curriculum guide and the teachers' need to construct curriculum that is responsive to students.

Remillard's (1999, 2000) study of two teachers using a textbook that represented a commercial publisher's response to the NCTM *Standards* (1989) also examined teachers' participation with curriculum. The study illustrates how two fourth grade teachers interacted with the same text in different ways to construct contrasting opportunities for student learning. The analysis highlights the ways the teachers read the textbook and explores the factors that contributed to different approaches to reading. Not only did the two teachers read entirely separate features of the text (exercises for students versus supplementary activities), they also read for different purposes (potential activities and assignments versus big ideas to guide planning). These contrasting uses of the textbook resulted in different plans from the same lesson in the text.

Studies like these that frame and examine curriculum use as an interactive process not only capture how teachers interpret curriculum materials, but focus attention on the role the materials play in this process. They illustrate the complexity of transformation from the written to the intended curriculum.

While highlighting different aspects of the teacher-curriculum relationship, the above variations in the way curriculum use is conceptualized in the literature also point to fundamental differences in theoretical and conceptual assumptions underlying the research. These differences, when not made explicit, further complicate efforts to examine findings across studies and illustrate the need for greater clarity in how these constructs are conceptualized.

The relationship between the written and intended curriculum (the first and second boxes of Figure 8.1) has been neglected in most studies of how curriculum influences student learning. Yet the set of studies reviewed here point to important variations in curriculum use that are introduced even before the lesson begins. These studies are important because they challenge the assumption that curriculum materials tend to be implemented uniformly across teachers, schools, and districts. If research suggests that the curriculum is altered the minute that a teacher begins to read it, then the assumption that curriculum materials are single-handedly—or even primarily—responsible for student performance becomes questionable and the need to broaden the logic to include a discussion of how teachers interpret the curriculum becomes apparent. Thus, we see this set of studies as laying the first stone in the foundation of a chain of reasoning, evidence and argument that must underlie future studies of how curriculum influences student learning.

Throughout this chapter, we call for this chain to be broader, more inclusive, better-articulated, and more internally coherent than what currently exists. As we have already noted, the studies reviewed in Sections One and Two reveal the need for greater consistency with respect to the dimensions that are examined when analyzing the curriculum materials (phase one of the framework) and curriculum interpretations (phase two of the framework). Another point raised for us by these studies concerns the consistency with which the term *fidelity of implementation* is used (fidelity is an important concept in the "following vs. subverting" approach to studying curriculum use). More specifically, might "fidelity" mean something different when one is discussing a standards-based versus conventional curriculum materials? If conventional materials—as described earlier—present content and exercises in a straightforward manner, might not the attainment of fidelity be, not only easier to achieve, but also easier to measure? One would

examine the extent to which teachers provided the correct definitions, examples, and procedures and whether they monitored student practice accurately. Standards-based curricula, as noted earlier, tend to present information indirectly, relying on tasks—and students' work on those tasks—to expose the concepts to be learned, thereby placing considerable demand and discretion on teachers to help students correctly surface and explicate concepts and desirable ways of thinking and reasoning. Here, one would need to examine the extent to which teachers' ways of assisting students was compatible with this indirect style of teaching, the extent to which the teacher listens to and "pulls from" students important ideas, and, if and how the students correctly surface the intended material. In the first case, one appears to be measuring fidelity to a given set of teacher procedures, in the second, the fidelity is to an underlying philosophy and theory of learning.

SECTION THREE: THE ENACTMENT OF CURRICULA IN CLASSROOMS

This section examines the ways in which curricular tasks are set up and enacted during instruction. Here our focus moves beyond teachers' intentions to the examination of what actually occurs as curriculum materials are enacted in the classroom—the third phase of curricular use shown in Figure 8.1. We begin this section by discussing the various ways in which curriculum enactment has been studied and providing a rationale for the approach taken herein—a focus on mathematics tasks. We continue by exploring the source and nature of mathematical tasks that are used as the basis of instruction in our nation's classrooms. We then turn our attention to research that illuminates the ways in which mathematical tasks are set up and enacted by classroom teachers and their students and the processes that influence the ways in which tasks actually unfold in the classroom.

Ways in Which Curriculum Enactment Has Been Studied

Studies that can shed light on the enactment of curriculum in the classroom vary with respect to the aspects of instructional practice to which they have attended. Over the past decade, researchers have conducted studies focused on classroom discourse (e.g., O'Conner, 2001), questioning (e.g., Boaler & Brodie, 2004), intellectual authority (e.g., Wilson & Lloyd, 2000) and on normative practices (e.g., Boaler & Staples, in press) in classrooms in which standards-based and conventional curricula were being used. While not focusing directly on curricular enactment, these studies provide insight into the challenges and possibilities of orchestrating teaching and learning interactions around standards-based curricular tasks.

In this section, we organize our discussion of these and other studies through the conceptual lens of mathematical instructional tasks. We have made this decision for several reasons. First, classroom instruction is generally organized and orchestrated around mathematical instructional tasks. That is, students' day-to-day work in mathematics classrooms consists of working on a tasks, activities, or problems. For example, an analysis of 100 eighth grade lessons revealed that the delivery of content "was accomplished primarily by working through problems" (NCES, 2003, p. 144). Second, the tasks with which students engage determines what they learn about mathematics and how they learn it. According to Doyle (1983, p.161), "tasks influence learners by directing their attention to particular aspects of content and by specifying ways of processing information." Finally, tasks are a way of framing how researchers have looked at the enactment of curriculum (e.g., Doyle 1983 1988). And, because a discussion of tasks typically implicates many of the dimensions discussed above (i.e., discourse, questioning, authority structures, normative practices), we are able to discuss many of these attributes of implementation under the overall umbrella of task.

The Source and Nature of Mathematical Tasks

We define mathematical tasks as classroom activities the purpose of which is to focus students' attention on a particular mathematical idea. Tasks include expectations regarding what students are expected to produce, how they are expected to produce it, and the resources available for so doing (Doyle, 1988; Stein et al., 1996). Curricular materials or textbooks are the main source of mathematical tasks used by teachers for classroom instruction. An analysis of responses to teacher questionnaires, administered under the auspices of the National Assessment of Educational Progress in 2000, revealed that more than two-thirds of students at grades 4 and 8 had teachers who reported that students worked on problems from the textbook on a daily basis (Grouws et al., 2004). An additional 20 percent of students at both grades 4 and 8 had teachers who reported using tasks from the textbook once or twice a week. Although these percentages represented a significant decrease in textbook use from 1992 (Grouws et al., 2004), these data continue to

Task A **Martha's Carpeting Task**	**Task B** **The Fencing Task**
Martha was recarpeting her bedroom, which was 15 feet long and 10 feet wide. How many square feet of carpeting will she need to purchase?	Ms. Brown's class will raise rabbits for their spring science fair. They have 24 feet of fencing with which to build a rectangular pen to keep the rabbits. a. If Ms. Brown's students want their rabbits to have as much room as possible, how long would each of the sides of the pen have to be? b. How long would each of the sides be if they had only 16 feet of fencing? c. How would you go about determining the pen with the most room for any amount of fencing? Organize your work so that someone else who reads it will understand it.

Figure 8.3 Two different mathematical tasks that involve the calculation of area (Stein et al., 2000, pp. 1–2)

make salient the centrality of textbooks in classroom instruction. Data from the most recent TIMSS video study provide additional evidence of the centrality of textbooks. Specifically, 98% of the lessons from the U.S. analyzed in this study used a textbook or a worksheet (NCES, 2003).

As we have discussed earlier in this chapter, curricular materials vary considerably with respect to the nature of the mathematical tasks that are found within them. For example, in comparison to conventional curricula, standards-based curricula have more contextual problems, more tasks that can be solved by using a range of strategies, and fewer exercises that require only application of procedures (Senk & Thompson, 2003). Making distinctions between tasks is important because all tasks do not provide the same opportunities for students' thinking and learning. Tasks that ask students to perform a memorized procedure in a routine manner lead to one type of opportunity for student thinking; tasks that demand engagement with concepts and that stimulate students to make connections lead to a different set of opportunities for student thinking.

Consider, for example, the two tasks shown in Figure 8.3. Task A (Martha's Carpeting Task) requires the simple application of the formula for finding the area of a rectangle (i.e., $A = l \times w$, where l and w refer to the length and width of a rectangle respectively). There is no ambiguity about what needs to be done in order to solve this problem or how one should go about doing it. Therefore it can be viewed as a task with low-level cognitive demands. By contrast in order to solve Task B (The Fencing Task), students must do more than apply a formula in order to be successful. They must generate and test different pen configurations in order to identify the pen that yields the maximum area using two different lengths of fencing (first 24 and then 16 feet). Students must then generalize beyond the two cases in order to determine the dimensions of the pen that will yield the largest area for *any* amount of fence. As a result, Task B can be viewed as a task with high-level cognitive demands. Students must construct their own approach for solving the task as none is obvious or prescribed. Although the area formula may be used to determine the area of various pen configurations, the task also requires students to engage in additional mathematical thinking and reasoning that includes looking for patterns, making and testing conjectures, and finding a generalization that can be explained and justified.

Hence, the tasks with which students become engaged in the classroom form the basis of their opportunities to learn *what* mathematics is and *how* one does it (Doyle, 1983, 1988). What students can learn from problems such as Martha's Carpeting Task is significantly different from what they learn from the Fencing Task. Over time, the cumulative effect of classroom-based tasks is students' implicit development of ideas about the nature of mathematics—about whether mathematics is something that they personally can make sense of, and how long and how hard they should have to work to do so.

Since the introduction of the *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) there has been an attempt to describe the types of tasks that promote and develop students' understanding of mathematical concepts and ideas. Although these descriptions differ with respect to the actual language used to describe the nature of the activities in which students should engage, they share a common focus on developing students' capacity for non-algorithmic thinking. For example, *worthwhile mathematical tasks* (NCTM, 1991) are described as "ones that do not separate mathematical thinking from mathemati-

cal concepts or skills, that capture students' curiosity, and that invite them to speculate and to pursue their hunches (p. 25)." Hiebert and his colleagues (Hiebert et al., 1997) have argued that in order for students to build mathematical understandings, the tasks with which they engage "must allow the students to treat the situations as problematic, as something they need to think about rather than as a prescription they need to follow" (p. 18). Such experiences, in their view, leave behind important insights into the structure of mathematics and strategies for solving classes of problems. More recently, Horn (2005, p. 22) has used the term "groupworthy" to describe tasks that "illustrate important mathematical concepts, allow for multiple representations, include tasks that draw effectively on the collective resources of a groups, and have several possible solution paths." While similar in some ways to the task descriptions provided by NCTM and Hiebert and his colleagues, Horn's notion of groupworthy tasks also makes salient the need to provide students who are working collaboratively—an organizational structure often found in classrooms that use standards-based curricula—with tasks that allow for multiple entry points so that group members who bring different strengths to the table can contribute to solving the task at hand.

Stein and her colleagues (Henningsen & Stein, 1997; Smith & Stein, 1998; Stein et al., 2000; Stein et al., 1996; Stein & Lane, 1996; Stein & Smith, 1998) have provided a taxonomy of mathematical tasks based on the kind and level of thinking required to solve them. From this perspective, mathematical tasks are viewed as placing *high-level* cognitive demands on students when they appear to engage students in the processes of active inquiry and validation (what Stein and colleagues refer to as "doing mathematics") or encourage them to use procedures (broadly defined to include standard and nonstandard procedures, formulas, and algorithms) in ways that are meaningfully connected to concepts or understanding. Tasks that encourage students to use procedures, formulas, or algorithms in ways that are not actively linked to meaning; or that consist primarily of memorization or the reproduction of previously memorized facts are viewed as placing *lower-level* cognitive demands on students. Examples of tasks that would be classified at each of the four levels of cognitive demand in the Stein et al. taxonomy are shown in Figure 8.4. In the TIMSS Video Study (NCES, 2003; Stigler & Hiebert, 2004) a similar distinction was made between low-level tasks that can be solved with basic computation and procedures (*using procedures*) and high-level tasks that focus on concepts and connections among mathematical ideas (*making connections*).

In addition to providing a taxonomy for classifying mathematical tasks, Stein and her colleagues also provide a framework for tracking the cognitive demands of mathematical tasks as they unfold during instruction and for exploring the connection between instruction and student learning. The Mathematical Tasks Framework (MTF) distinguishes three phases through which tasks pass as they unfold during a lesson (Stein et al, 1996): First, as they appear in curricular or instructional materials (i.e., on the printed pages of textbooks, ancillary materials, or as created by teachers); next, as they are set up or announced by the teacher; and finally, as they are actually enacted by students and the teacher in the classroom—in other words, the way in which students actually go about working on the task. All of these, but especially the enactment phase, are viewed as important influences on what students actually learn.

This research suggests that the cognitive demands of a task can change as the task unfolds. For example, the task that appears in curricular materials is not always identical to the task that is set up by the teacher in the classroom (reflecting the interpretive processes discussed in Section Two) and, this task, in turn, is not always identical to the task that the students actually do. Between the set-up and implementation phases, tasks can transform for a variety of reasons, many of which have to do with the press of the classroom environment. It is interesting to note, however, that tasks that are set-up at a low-level are nearly always implemented as intended, a point to which we will return (Stein et al., 1996).

In the remainder of this section, we use the Mathematical Tasks Framework as an organizing frame to discuss large and small-scale studies that provide insights into the ways in which mathematics tasks are enacted in the classroom.

Setting Up and Implementing Mathematical Tasks

Research has shown that maintaining high-level cognitive demands during implementation is much more difficult than selecting and setting up high-level tasks. In a study involving 144 lessons selected to be representative of instruction at four middle schools that participated in the QUASAR Project (Stein et al., 1996; Henningsen & Stein, 1997), three-quarters of the tasks were set-up in ways that demanded that students either engage in the active processes of "doing mathematics" or use procedures with connections to concepts, meaning, or understanding (Stein et al., 1996). The study also showed, however, that the higher the demands that a task placed on students at the set-up phase, the less likely it was for the task to be carried out at that level during the implementa-

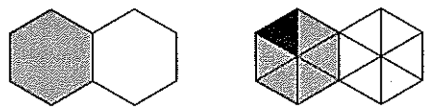
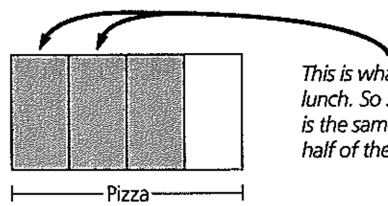
Lower-Level Demands	Higher-Level Demands
Memorization What is the rule for multiplying fractions? *Expected Student Response:* *You multiply the numerator times the numerator and the denominator times the denominator* OR *You multiply the two top numbers and then the two bottom numbers.*	**Procedures with Connections** Find 1/6 of 1/2. Use pattern blocks. Draw your answer and explain your solution. *Expected Student Response:*  *First you take half of the whole which would be one hexagon. Then you take one-sixth of the half. So I divided the hexagon into six pieces which would be six triangles. I only needed one-sixth so that would be one triangle. Then I needed to figure out what part of the two hexagons one tiangle was and it was 1 out of 12. So 1/6 of 1/2 is 1/12.*
Procedures without Connections Multiply: $\frac{2}{3} \times \frac{3}{4}$ $\frac{5}{6} \times \frac{7}{8}$ $\frac{4}{9} \times \frac{3}{5}$ *Expected Student Response:* $\frac{2}{3} \times \frac{3}{4} = \frac{2 \times 3}{3 \times 4} = \frac{6}{12}$ $\frac{5}{6} \times \frac{7}{8} = \frac{5 \times 7}{6 \times 8} = \frac{35}{48}$ $\frac{4}{9} \times \frac{3}{5} = \frac{4 \times 3}{9 \times 5} = \frac{12}{45}$	**Doing Mathematics** Create a real-world situation for the following problem: $\frac{2}{3} \times \frac{3}{4}$ Solve the problem you have created without using the rule and explain your solution. *One Possible Student Response:* *For lunch, Mom gave me three-fourths of the pizza that we ordered. I could only finish two-thirds of what she gave me. How much of the whole pizza did I eat?* *I drew a rectangle to show the whole pizza. Then I cut it into fourths and shaded three of them to show the part Mom gave me. Since I only ate two thirds of what she gave me, that would be only two of the shaded sections.* *Mom gave me the part I shaded.*  *This is what I ate for lunch. So 2/3 of 3/4 is the same thing as half of the pizza.*

Figure 8.4. Examples of tasks at each of the four levels of cognitive demand.

tion phase. Indeed the kind of tasks that reformers have suggested as most essential for building students' capacities to think and reason mathematically (high-level tasks) appear to be the very tasks that students and teachers have the most difficulty carrying out in a consistent manner. Overall, tasks that were set up to require a high level of cognitive engagement were found to decline into less demanding student engagement more than half of the time (in 62 out of 107 tasks or 58%).

The difficulty teachers in the United States have enacting tasks at a high level is echoed in the results of the recent TIMMS video study. In this study, a random sample of 100 8th grade mathematics classes from each of seven countries was videotaped during the 1999 school year. Although 17 percent of the problems used by teachers in the U.S. were coded as high level (*making connections*), none of these problems was implemented as intended (NCES, 2003; Stigler & Hiebert, 2004). Instead, most of the making-connections problems were transformed into procedural exercises. Hence, the authors concluded, U.S. 8th grade students spend most of their time in mathematics classrooms practicing procedures regardless of the nature of the tasks they are given.

The *Inside the Classroom* study, conducted by Horizon Research, provides additional insight into the nature of mathematics instruction in the United States (Weiss & Pasley, 2004). In a study of 364 lessons, drawn from representative K–12 mathematics and science classrooms, only 15 percent of the lessons "were structured and implemented in a manner that engaged students with important mathematics or science concepts" and were viewed as "very likely to enhance student understanding of these concepts and to develop their capacity to do mathematics or science successfully" (p. 25). The majority of lessons (59%) were rated as low quality and were deemed unlikely

to enhance students' understanding of mathematics or science concepts. Interestingly, the authors also report that the quality of lessons was not associated with a particular approach to teaching—both reform oriented and traditional lessons were found in each of the three categories (i.e., low quality, medium quality, high quality).

Case studies of teachers attempting to use challenging tasks and curricula in their classrooms provide insights into what actually occurs as these tasks are enacted by teachers and students during instruction. In their study of the early efforts of teachers to implement mathematics instructional reform in California, EPPS researchers observed an odd combination of old ways and new practices coexisting (Cohen et al., 1990). This was most evident in the case of Mrs. O who on the surface appeared to embrace reform, but a closer look revealed that not much had changed (Cohen, 1990). While Mrs. O used innovative instructional materials and activities that were designed to help students make sense of mathematics, she used them in a way "that conveyed a sense of mathematics as a fixed body of knowledge of right answers rather than as a field of inquiry" (Cohen, 1991, p. 19). Students were not asked to explain correct or incorrect solutions or the strategies used to derive them and there was no communication among students.

The mélange of old methods and new materials that characterized Mrs. O's practice highlights the challenges faced by teachers as they have endeavored to use new tasks and curricula in their classrooms and to take on new roles in the classroom. Other studies provide insights into the nature of the challenges faced by teachers who have attempted to use new tasks in new ways. For example, teachers struggle with relinquishing authority in the classroom (Wilson & Goldenberg, 1998; Wilson & Lloyd, 2000; Wood, Cobb, & Yackel 1991), ensuring that students feel successful as they work on more challenging mathematical tasks (Smith, 2000), knowing when to ask questions and when to provide information (Romagnano, 1994), and providing an appropriate amount of support and structure (Lloyd, 1999). These studies and others make it clear that taking on these new roles and responsibilities is not easy for teachers. As EPPS researchers (Cohen et al., 1990, p.163) have concluded, "changing one's teaching is not like changing one's socks"—but rather it requires a deep-seated change in belief about what it means to teach and learn mathematics." In Section Four, we discuss the role that teachers' beliefs and other mediating factors play in influencing the transformation of the written curriculum to the intended curriculum and the intended curriculum to the enacted curriculum.

Investigating Processes Involved in Task Implementation

Here we turn our attention to classroom processes that influence what teachers and students actually *do* during classroom instruction. What students do during instruction depends, to some extent, on the normative practices that have been agreed upon either explicitly or implicitly by the students and teacher. According to Carpenter and Lehrer (1999, p. 26), "although the selection of appropriate tasks and tools can facilitate the development of understanding, the normative practices of a class determine whether they will be used for that purpose." Hence we confine our discussion here to what happens during task implementation—the actions and interactions of teachers and students as they work on mathematical tasks. In Section Four, we discuss the factors (shown in the oval in Figure 8.1) that influence these interpretive processes and in so doing provide plausible explanations for the transformations that often occur during the task implementation phase.

In the previously cited study of QUASAR Project middle schools (Henningsen & Stein, 1997; Stein et al., 1996), a handful of patterns emerged that capture characteristic ways in which high-level tasks unfold in the classrooms of teachers who are attempting to reform their instruction so as to be more compatible with the *Standards* (NCTM, 1989, 2000). These patterns and the processes associated with them are described below.

Some tasks that were set up to place high levels of cognitive demand on student thinking were indeed implemented in such a way that students thought and reasoned in complex and meaningful ways. When this happened, teachers generally drew on a number of processes in order to support students' engagement in a way that maintained the demands of the task. As shown in the second column of Table 8.2, these processes include scaffolding of student thinking (i.e., assisting student thinking in a manner that preserves task complexity), modeling of high-level thinking and reasoning by the teacher or more capable peers, pressing for explanation and meaning, and selecting tasks that built on students' prior knowledge.

Other tasks that were set up to place high levels of cognitive demand on students' thinking, however, exhibited declines in terms of how students actually went about working on them. When tasks declined, a different set of processes tended to be operating in the classroom environment (see first column in Table 8.2). These processes involved a variety of teacher, student, and task-related conditions, actions, and norms. Although tasks can decline in several different ways,

Table 8.2 Processes Associated with Maintenance and Decline of High-Level Cognitive Demands

Processes Associated with the Decline of High-Level Cognitive Demands	Processes Associated with the Maintenance of High-Level Cognitive Demands
Routinizing problematic aspects of the task	Scaffolding of student thinking and reasoning
Shifting the emphasis from meaning, concepts, or understanding to the correctness or completeness of the answer	Providing a means by which students can monitor their own progress
Providing insufficient time to wrestle with the demanding aspects of the task or so much time that students drift into off-task behavior	Modeling of high-level performance by teacher or capable students
Engaging in high-level cognitive activities is prevented due to classroom management problems	Pressing for justifications, explanations, and/or meaning through questioning, comments, and/or feedback
Selecting a task that is inappropriate for a given group of students	Selecting tasks that build on students' prior knowledge
Failing to hold students accountable for high-level products or processes	Drawing frequent conceptual connections
	Providing sufficient time to explore

one common pattern is into tasks in which students use procedures without connections to meaning. (See Henningsen & Stein, 1997 for a examples of patterns of maintenance and decline of high level tasks.)

Instead of engaging deeply and meaningfully with the mathematics, students ended up utilizing a more procedural, often mechanical and shallow approach to the task. In this type of decline, one of the most prevalent factors operating in the environment was teachers' "taking over" and doing the challenging aspects of the tasks for the students. High-level tasks tend to be less structured, more difficult, and longer than the kinds of tasks to which students are typically exposed. Students often perceive these types of tasks as ambiguous and/or risky because it is not apparent what they should do, how they should do it, and how their work will be evaluated (Doyle 1988; Romagnano, 1994). In order to deal with the discomfort that surrounds this uncertainty, students often urge teachers to make these types of tasks more explicit by breaking them down into smaller steps, specifying exact procedures to be followed, or actually doing parts of the task for them. Should the teacher succumb to such requests, the challenging, sense-making aspects of the task are reduced or eliminated, thereby robbing students of the opportunity to develop thinking and reasoning skills and meaningful mathematical understandings.

A review of the processes in Table 8.2 suggests the central role of teachers' questions to the outcome of a lesson. Asking questions that scaffold or support students' continued engagement with a task and that press students to explain and justify their thinking are key to sustaining the cognitive demands of mathematical tasks. Alternatively, failure to ask questions that go beyond the correct answer or that communicate accountability for thinking and reasoning are associated with the decline of high level tasks. The nature of teachers' questioning and its impact on students' opportunities to learn are highlighted in both large and small-scale studies. For example, in the study of 350 representative mathematics and science lessons, Weiss and Pasley (2004) indicated that effective questioning was key in helping students develop an understanding of mathematical concepts and in making connections, yet rare in the observed classes. According to the authors, such scaffolding allows teachers to monitor students' understanding and encourages students to thinking more deeply and critically. The study suggests, however, that teachers more frequently asked questions that focus on getting the correct answer rather than on helping students make sense of mathematics concepts.

In a comparative study of mathematics teachers in three high schools using standards-based vs. conventional curricula, Boaler and Brodie (2004) found that teachers using standards-based curricula asked a broader range of questions than those who used a conventional curricula. In particular, nearly all of the questions (95%) asked by the teachers using conventional curricula fell into the category of procedural questions. While teachers using standards-based curricula also asked many procedural questions (60–75% of the questions asked were categorized as such) they also asked a large percentage of questions that were classified as conceptual and probing. Boaler and Brodie (2004, p. 780) argue that teachers' questions play an important role "in shaping the nature of classroom environments and the mathematical terrain that is traversed . . . and the cognitive opportunities offered to students."

Several case studies also point to the critical relationship between questioning and maintaining the integrity of the task (e.g., Smith, 2000; Wood et al., 1991). For example, in a study of a second grade teacher who was implementing standards-based mathematics materials, Wood et al. (1991) note that initially the teacher was unsure how to deal with the various procedures, solutions, and incorrect answers that students came up with during their explorations. The teacher's initial attempt to deal with this challenge resulted in beginning with a student's incorrect response and leading the student through a series of questions that would ultimately lead to the answer the teacher had in mind. According to Wood et al. (1991), "as the teacher reflected on the use of this approach later, she recognized that attempting to guide students in this manner was just another way for the teacher to ensure students get the right answer, whether they understand how to or not" (p. 604).

Related to the issue of what *type* of question to ask is the challenge of determining *when* to let students struggle without teacher input, *when* to ask leading questions, and *when* to tell students something directly (NCTM, 1991). These decisions are at the heart of what Romagnano (1994) refers to as "The Ask Them or Tell Them Dilemma." This dilemma grew out of the pull and tug of when to withhold and when to provide information to students. Romagnano found that it was the frustration and lack of clarity resulting from both the nondirective questions and the use of more complex problems that caused students to disengage. While consistent with the findings regarding the implementation of novel tasks (Doyle, 1988), this presented a dilemma to Romagnano, the teacher with whom he worked, and to many other teachers who are engaged in such work. Romagnano indicated that, "being directive was a problem because I knew that when I was that way, I reduced the chances that any significant mathematics would be learned" (1994, p. 123).

These studies raise important issues about the teacher's role in "discussion-intensive teaching" (Chazan & Ball, 1999) that is often intertwined with the use of the kind of high-level tasks found in standards-based curricula. Although teachers are told *not* to tell, they are given no explicit direction regarding what they could or should do instead. This leaves teachers struggling to determine *how* to support students without taking away the challenge *before* they completely disengage from activity in frustration. Chazan and Ball (1999, p. 9) argue that for teachers to direct a discussion productively, they must have "a repertoire of ways to add, stir, slow, redirect the class's work."

In their study of teachers at Railside, Boaler and Staples (in press) indicate that a feature of the curriculum—one that could not be seen in a review of the curricular materials themselves—was the follow-up questions that teachers asked students. According to the authors, these questions "shaped the course of implementation" (p. 19). The questions, written prior to teaching the lesson, provided teachers with specific ways of focusing students on the key mathematical ideas in the lesson leaving less "in the moment" decision-making regarding the next instructional move.

In this section, we have reviewed the changes that often occur once curricular tasks are unleashed in real classroom settings. By adding new dimensions to our understanding of how curricula are transformed over time, they provide further building blocks in our evolving chain of logic regarding how students learn from curriculum. The studies reviewed in this section suggest, once again, that the introduction of human interaction with curriculum materials brings variation to the information and styles of learning to which students will be exposed. In the previous section, the variation was introduced by the interpretive processes of the teacher "reading" the curriculum materials. In this section, variation is introduced by the flux of the classroom life—a space comprised of students as well as teachers. Instead of just one person interpreting the curriculum (the teacher as he or she plans), there is now a roomful of students interpreting the curriculum tasks and materials and bouncing off of each others' interpretations. As the teacher responds to these interpretations, the task is often transformed into a learning opportunity that is quite different from what was intended by the curriculum developers.

Interestingly, although not the specific focus on any study of which we are aware, the conceptual ideas and empirical findings presented herein suggest that one might expect less variation in the classroom-based enactment of conventional as opposed to standards-based curricula. Most of the studies cited above were conducted in classrooms in which teachers were using standards-based curricula or similarly inspired reform materials. When teachers set up instructional tasks in the way outlined by the materials, the stage was set for the study of how teachers and students enact high-level task (since these kinds of tasks comprise the majority of activities in standards-based materials). However, as noted earlier, low level tasks tended to implemented as intended (Stein et al., 1996). This is because there is much less ambiguity regarding what to do and how to do it. Thus, one would expect less variation in how teachers enact tasks that are found in conventional curricula (since these kinds of tasks—procedural and

definitional activities—comprise the majority of conventional curricula).

This observation reinforces the point made at the end of the previous section regarding the concept of fidelity. There, we noted that the implementation of curricular tasks with fidelity would be expected to be more attainable and measurable with conventional as opposed to standards based curricula. Here we have extended the idea to encompass the notion that enactment of standards-based curricula can logically be expected to lead to greater variability than the enactment of conventional curricula. This is important because—as noted throughout this chapter—it is not the materials themselves but rather how students' experience the materials in the classroom that determines what students will learn. If standards-based classrooms have more variable implementation, then predicting what students will learn from them becomes more difficult.

SECTION FOUR: EXPLAINING TRANSFORMATIONS WITHIN AND BETWEEN DIFFERENT PHASES OF CURRICULUM USE

The preceding sections detail some of the transformations that occur between the written and intended curriculum and within the enactment phase (see Figure 8.1). Research on mathematics teaching and teachers' use of curriculum materials highlights the ways teachers read and interpret written curriculum materials differently (Section Two) and planned tasks and instructional designs are reconstructed by students and teachers as they unfold in real-time lessons (Section Three). In addition to identifying curricular transformations, much of the research seeks to explain them by identifying factors that influence transformations. The teacher figures most prominently in these explanations. However, much of this literature recognizes that the reasons underlying the ways teachers and students transform curriculum are multi-faceted and complex. In addition to individual teacher characteristics, scholars have identified students, the teaching context, and the curriculum itself to be influential in these processes. In the following sections, we discuss the kinds of factors that have been identified in the research. Rather than providing an extensive review of this research, our aim is to delineate those factors that appear influential across the body of studies. The specific studies cited are offered as illustrations.

The Teacher Matters

Studies that examine the way that teacher-related factors influence how teachers use materials in planning and enacting curriculum are most prominent in the literature. The factors most studied include teachers' beliefs about mathematics, teaching, and learning; their knowledge of mathematics; and their experiences as teachers and as students. More recently researchers have begun to conceptualize additional influencing factors, including teacher identity and their stance or orientation toward curriculum materials.

Beliefs and Knowledge

The research that focuses on the role that teachers' beliefs and knowledge play in teachers' curriculum use is part of a larger body of research on the influences of beliefs and knowledge on teaching practices more generally. In fact, the 1992 *Handbook* devoted an entire chapter to the role of teachers' beliefs in mathematics teaching (Thompson, 1992) and a second chapter to the role of teacher knowledge (Fennema & Franke, 1992). The research reviewed in these two chapters demonstrates the critical role teachers' beliefs about mathematics, teaching, and learning and their knowledge of mathematics and students' learning play in influencing their pedagogical and curricular decisions. We limit our discussion here to the portion of this research that is specific to curriculum use. A substantial portion of this research focuses on a) teachers' beliefs about the nature of mathematics and the nature of knowledge, b) teachers' goals for students and their beliefs about purposes of school, and c) teachers' mathematical knowledge. In most cases, these beliefs are tightly intertwined with one another and cannot be examined in isolation (Putnam, Heaton, Prawat, & Remillard, 1992). In the following sections we discuss examples of studies that illustrate how these beliefs influence curriculum use.

Examinations of teachers' beliefs about mathematics, how it is learned, and the nature of mathematical knowledge have figured prominently in studies of teachers' use of standards-based curriculum because these materials offer views of mathematics that conflict with those typically held in mainstream culture. Indeed, much of this research illustrates the ways that teachers' beliefs about mathematics and how it is learned influence how they interpret and use curriculum materials. This influence is particularly evident when conflicts exist between teachers' beliefs and the ideas embraced by the curriculum designers. A number of researchers have pointed to the deeply rooted nature of teachers' beliefs about mathematics (Wilson & Goldenberg, 1998) as an explanation for both sub-

stantial departures from and resistance to suggestions offered by standards-based curricula (Chavez, 2003; Lloyd & Wilson, 1998; Romberg, 1997). Other studies have attributed different teachers' uses of the same curriculum to substantial differences in the teachers' beliefs about mathematics and how students learn it (e.g., Collopy, 2003; Lloyd, 1999; Remillard, 1999).

While discussions of teachers' beliefs about mathematics permeate research on teachers' use of curriculum resources, there is general agreement that they should not be viewed in isolation. Putnam et al., (1992) used case studies of elementary teachers' responses to new curricula and new state policy, to illustrate how teachers' beliefs about mathematics were tightly intertwined with their beliefs about knowledge, teaching, and learning more generally. Other researchers have identified additional aspects of curriculum materials that conflict with beliefs commonly held amongst teachers. Stephens (1982) and Donovan (1983), for instance, illustrated how conflicts between teachers' beliefs about classroom control and management and purposes of school and those ideas represented in an innovative curriculum led teachers to ignore or change key features in the curriculum.

Limits in teachers' mathematical knowledge are frequently used to explain the ways that teachers use curriculum materials, particularly materials designed to foster understandings of concepts and relationships underlying standard mathematical procedures. Heaton (1992) and Cohen (1990) provide two examples of elementary teachers failing to appreciate the mathematical complexity underlying activities suggested in curriculum. Both teachers they report on used interactive mathematics tasks drawn from standards-based curriculum programs without developing the underlying mathematical ideas. Similarly, in their two-year study of two seventh grade mathematics teachers using a standards-based, middle-school curriculum, Manouchehri and Goodman (1998) found the teachers' mathematical knowledge to be the greatest influence on how they used the curriculum.

Orientation

Factors other than teachers' beliefs about mathematics teaching and learning have been found to influence their use of materials. Some studies indicate that teachers' perceptions of curriculum materials or textbooks as a particular genre of teacher resource influence how they engage and use them. In a study of two teacher education programs, Ball and Feiman-Nemser (1988) found that the majority of preservice teachers tended to associate textbooks with traditional and undesirable teaching practices. As a result, they were reluctant to draw on these resources when planning mathematics lessons. Remillard and Bryans (2004) used the term "orientation" to refer to a teacher's stance toward curriculum materials in teaching. These researchers found this orientation to be influential in how and whether teachers used the curriculum regardless of the match or mismatch of the ideas in the curriculum to the teacher's view about mathematics teaching.

Professional Identity

Researchers have also found that teacher's professional identity, or how they see themselves and their roles as teachers, influences curriculum use. Spillane (2000) refers to teachers' identity as "who they are, their sense of self, and their habits of mind . . . an individual's way of understanding and being in the world" (p. 308). The concept of identity builds on and extends the large body of work that considers how teachers' knowledge and beliefs influence their curricular decision making and practice. Identity, as a construct, integrates what one knows, feels and is inclined to do in a particular context into an inseparable whole, making activity, rather than knowledge, central. While knowledge is often viewed as static, identity is active. Further, the notion of identity highlights the contextual and social nature of knowing and being. Identity is a social construct that develops in relation to others and particular contexts.[14] "Identities develop in and through social practices" (Boaler & Greeno, 2000, p. 173). That is, teachers' professional identities are produced in relation to their work as teachers in classrooms with students. And, as Spillane (2000) and Drake and Sherin (2006) suggest, identities are subject-matter specific. The role the particular subject matter plays in a teacher's professional identity is, perhaps, best illustrated by Spillane's case of an elementary teacher who routinely facilitated inquiry-oriented discussions amongst her fifth graders in the area of reading, writing, and grammar. Her mathematics instruction, on the other hand, tended to focus on directing students to memorize and follow procedural rules.

A significant component of teachers' professional identity is how they construct their roles in relation to students. Many teachers, for instance, associate good teaching with telling and showing students what to do,

[14] For organizational purposes, we have placed professional identity under the heading of the teacher. However, as this discussion suggests, identity is a social and context-specific phenomenon and, thus, embraces influential factors discussed in the following sections, including students, context, and curriculum materials.

whereas, standards-based curriculum materials outline a much less didactic role for the teacher. J. Smith's (1996) analysis of the fundamental conflicts between factors that tend to positively influence teachers' sense of their own efficacy, as outlined by self-efficacy research, and the view of teaching promoted by the NCTM Standards helps to explain teachers' curriculum transformations. Frykholm (2004) found that using curriculum materials that conflicted with their ideas about good teaching resulted in considerable discomfort for teachers. He argued that using standards-based curriculum materials required teachers to develop tolerance for this discomfort. Lloyd (1999) observed a different kind of conflict between a teacher's identity and standards-based curriculum materials. One of the teachers in her study of teachers using a high school curriculum viewed herself as an innovative, project-based mathematics teacher and, consequently, found the curriculum overly restricting and difficult to follow closely.

Students Matter

A number of studies have revealed that students' responses to standards-based curricula appear to be influential in how teachers use new materials. Teachers tend to be concerned about the high level of independent thought, problem solving, and self monitoring demanded of students by the tasks found in standards-based curricula, expect that students cannot manage these demands, and consequently restructure or adapt the lessons to make them less complex and more readily accessible to students. As described previously, Stein et al. (1996) observed teachers reducing the complexity of tasks during instruction in response to students' struggles with high demand tasks. M. Smith (2000) associated the tendency to reduce task demand to teachers' concerns about student success. As the previous discussion on self-efficacy indicated, teachers' reluctance to allow students to struggle is associated with how they define and assess their role as teacher.

Some researchers have suggested that teachers' responses to challenging curriculum materials can be associated with perceived rather than actual concerns about students' difficulties. Wilson and Lloyd (2000) also observed that teachers' curricular decisions were often influenced by the "invisible hand of students" (Borasi, 1990). However, they found no evidence that the students in the classrooms they observed were having the kind of difficulties identified by the teachers. They suggest that "the invisible hand was teacher *perception* of student resistance, not student resistance per se" (p. 28).

A number of researchers have identified the challenges teachers face in sharing intellectual authority with students as another influential factor in how teachers use curriculum materials. As indicated earlier, standards-based curriculum materials include tasks and teaching recommendations that offer students a degree of autonomy and decision making that is not typical in traditional teaching practices in the United States. Many teachers, however, are not comfortable sharing authority with students and implement curricular suggestions in ways that are more structured and directive than recommended (Wilson & Goldenberg, 1998; Wilson & Lloyd, 2000) and in ways that provide a level of support and structure they deem necessary (Lloyd, 1999; Stein et al., 1996).

The Context Matters

Many studies have also identified the teaching context as an important factor in teachers' use of curriculum materials. Most of these studies highlight the ways features of the context constrain teachers from using the curriculum as intended by the developers or as fully as they would like. Some studies demonstrate the ways that elements of the context enable curriculum use. Some contextual features that figure prominently in this body of research include time, local cultures, and the extent and nature of teacher support.

Time

Limits on time for planning and to devote to mathematics instruction have both been identified as factors that influence how teachers use curriculum materials. Many of the standards-based curricula assume that a significant amount of time will be devoted to mathematics lesson—90 minutes or more. Moreover, the complexity of the mathematics and the instructional recommendations require that teachers spend more time preparing than they are accustomed to. In a study of middle school teachers using *CMP*, Keiser and Lambdin (1996) identify a number of issues related to time that influence how teachers use their materials. They identify conflicts between the time available for instruction and planning and the amount of time required. They also examined how teachers used time both in planning and during instruction. They argue that using standards-based curricula as intended requires flexibility in class scheduling and timing, a luxury infrequently afforded teachers.

Local Cultures

A number of studies have pointed to the ways in which the departmental, district, school, or community culture influences teachers' use of curriculum. This is particularly the case for standards-based curricula where a mismatch with the local norms is likely. As

mentioned above, these conflicts emerge around students' and teachers' roles during mathematics class, sharing authority with students, and norms for behavior (Floden et al., 1981; Lloyd, 1999; Manoucheri & Goodman, 1998; Wilson & Lloyd, 2000; Wood et al., 1991; Cobb, & Yackel 1991; Floden, et al., 1981).

Some researchers have focused attention on the norms of the school as a workplace for teacher learning. As noted earlier, the introduction of standards-based materials challenges what teachers know and how they think about mathematics, as well as their thinking regarding how students learn mathematics and what their role as teachers should be in the classroom. Research on teacher change suggests that teachers are more apt to change their approach to instruction when supported by a group of colleagues who are also struggling to learn innovative approaches to instruction (Coburn, 2001; Spillane, 1999). Some researchers who have explored the role of teacher-teacher interaction in supporting teacher reform in mathematics have utilized sociocultural concepts such as "communities of practice" to explain the ways in which groups of teachers influence each others' learning and adaptation to new forms of teaching (Cobb et al., 2003; Franke & Kazemi, 2001; Stein et al., 1998) More recently, Stein, Coburn and colleagues have utilized social capital as a theoretical construct to gain purchase on how teacher-teacher interaction influences teachers' experiences with the implementation of innovative curricula (Stein & Coburn, 2005).

Finally, since the introduction of NCLB, various policy-related factors have impacted what gets taught and how. The consequences associated with performing poorly on state-mandated tests, for example, have led to the introduction of pacing guides and other methods that McNeil along with others have suggested "narrow" the curriculum (McNeill, 2002). In addition, many districts have either begun with the reform of literacy instruction or have invested the greatest proportion of their resources in literacy. As such, the improvement of mathematics instruction often takes a back seat in overall school and district operations (Stein, Toure, Acquerelli, & Fergeson, 2003).

Teacher Support

A number of studies of teachers using standards-based curriculum materials report on the role of professional support in enabling and influencing teachers' work with the curriculum (Davenport, 2000; Remillard, 2000; Van Zoest & Bohl, 2002). Most of these studies align with what is known about the features of effective professional development in general. For example, effective professional development is content-based, promotes active learning, and is perceived by teachers to be part of an overall coherent program of teacher learning (Garet, Porter, Desimone, Birman, & Yoon, 2001). An additional feature that is often cited as critical in mathematics teacher professional development is the opportunity for teachers to engage in mathematics thinking and reasoning as learners, often exploring the same or similar tasks to what appears in the curriculum materials for students (Smith, 2001).

The Curriculum Matters

One factor that has the potential to influence transformations between written, intended, and enacted curriculum that has received minimal attention in the literature is the curriculum itself. How do characteristics or features of the particular curriculum influence how a teacher uses it? In order to consider this question, researchers must begin with analyses of curriculum materials themselves. This is an underdeveloped area of research. However, some of the ways curriculum materials have been characterized for the purpose of analysis include a) broad types, such as conventional versus standards-based, b) particular features or characteristics of the materials, and c) how they are designed to communicate with and educate teachers.

Conventional versus Standards-based Curricula

There is some evidence that teachers use standards-based curriculum materials differently than they use traditional curriculum, although there are few studies that compare use of two different curricula by the same teacher. Herbel-Eisenmann, Lubienski, and Id Deen (in press) undertook a comparative case study of a middle school math teacher using *Connected Mathematics,* a standards-based curriculum, with one class of students and a conventional textbook with another class. They found that the nature of the instruction was notably different across these two classes with respect to classroom organization and the types of tasks students were asked to do. However, these differences seemed closely related to the teacher's beliefs that students and their parents should have a say in the kind of instruction they received. In this setting, students opted into a traditional or reform track. Respecting their choices, this teacher adjusted her teaching practices to fit the curriculum she was using.

Many teachers are less flexible in their practices and find it difficult to use a curriculum that conflicts with their beliefs about mathematics and how it should be taught. In his analysis of seven studies of teachers using standards-based curriculum, Romberg (1997) noted that the mismatch between the teachers' underlying beliefs about mathematics and learning and

those implicit in the curriculum was a primary factor in how teachers used the curriculum. In his study of 53 teachers using either standards-based or conventional curricula, Chavez (2003) found that teachers using standards-based curricula felt less free to make adaptations and were less likely to see themselves as able to determine course goals and objectives.

Curriculum Features

Recently, scholars have questioned the value of applying such general classifications (standards-based or conventional) to analysis of influential factors in curriculum use, arguing that they mask substantial differences across curricula within categories (NRC, 2004)[15] and fail to provide reliable insights into how particular curricular features influence teachers' use (Remillard, 2005). Brown (2002) argues that understanding how a teacher uses curriculum resources and the resulting classroom practices requires an integrated analysis of the particular curriculum resources, the resources the teacher brings, and how they interact. Little research has been undertaken that examines these interactions, however the evidence provided here suggests this to be a fruitful area for future research.

The importance of taking into account the interactions between teachers and curriculum features is illustrated by Lloyd's (1999) findings from a study of two high school teachers using Core-Plus. One teacher found the curriculum too unstructured and struggled to navigate a curriculum where students' ideas were central. As a result, he tended to provide more support for students and more structure in the lesson than the curriculum suggested. The other teacher found the curriculum too structured for her taste.

Another feature frequently considered to be influential in how teachers use curriculum materials is sequencing—the way the material is ordered in the book. A commonly held assumption is that lessons near the end were more likely to be eliminated than those placed earlier in the book. To consider this hypothesis, Tarr et al., (2006) compared the lessons taught and omitted by 9 teachers using the same conventional textbook, *Glencoe*, and found that placement in the text was less influential in omission decisions than the particular topic of the lesson. Teachers omitted lessons throughout the book. Moreover, they omitted lessons on data analysis and probability at a significantly greater rate than lessons on number and operations or algebra.

Beyond content and sequencing, curriculum designers make a number of critical decisions about how the materials they produce are structured and communicated to the teacher. Many of the standards-based materials are designed to look substantially different from the conventional texts which were a mainstay in most classrooms in the U.S. We know little about how teachers engage these varied offerings.

Educative Curriculum

One characteristic common to the design of a number of the standards-based curriculum materials is their intent to communicate directly with teachers. Because these materials are relatively new, we know little about how teachers respond to or use these features. There are a few examples in the literature of teachers using these features to enhance their understanding of the purpose of particular lessons and to anticipate students' responses (Davenport, 2000; Rodriguez, 2000). There are also examples of teachers ignoring these features (Remillard & Bryans, 2004; Sherin & Drake, n.d.) or using them in different ways than were intended by the authors (Collopy, 2003). Drawing on research on teacher learning, Davis and Krajcik (2005) offer a set of design principles that might guide the development of educative curriculum materials. However, these principles are yet to be tested in practice.

The work cited in this section suggests possible explanations for why teachers interpret and enact curriculum in particular ways. Briefly, support can be found for factors that reside within the individual teacher, within students (or teachers' perceptions of students), within the context, and within the curriculum itself. These studies and their findings are important because they suggest additional pieces of the conceptual landscape that might be incorporated into both large and small-scale studies of curricular effectiveness.

These studies are also important from a practical perspective. The explanations that are offered for how teachers interpret and enact curriculum have primarily been generated from studies in which teachers have been attempting to adjust their instruction to be aligned with standards-based approaches to teaching and learning. Thus, if variations in curricular effectiveness are related to these factors, they suggest potential leverage points for interventions aimed at assisting teachers to enact standards-based curricula in ways that are more aligned with developers' intentions.

Finally, we believe that the study of curriculum materials and the manner in which they interact with the resources that teachers bring to the table (Brown,

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[15] See Stein and Kim (2006) for an exception; this study investigates similarities and differences between two standards-based curricula.

2002) deserves more attention. In this perspective, curriculum materials are viewed as tools that can enable or constrain teachers' thinking and actions (Wertsch, 1998). Research conducted from this perspective in science education has uncovered properties of curriculum materials that appear to influence instruction in important ways (Brown, 2002; Schneider & Krajcik, 2002). Stein and her colleagues (in press) have adopted this perspective in their research on elementary curriculum materials and are exploring how particular features of the materials interact with certain teacher characteristics (e.g., knowledge of mathematics for teaching), and with characteristics of the school environment (e.g., amount of teacher turnover; level and kind of social capital to which teachers have access). In doing so, their work attempts to change the question from, "Does Curriculum X work?" to the question: "Which curriculum works best under which conditions?"

SECTION FIVE: HOW THE ENACTED CURRICULUM INFLUENCES STUDENT LEARNING

In this section we examine the impact of curriculum on student learning by looking at the relationship between the enacted curriculum (the third box in Figure 8.1) and what students appear to learn from their instructional experiences (the final triangle in Figure 8.1). We have limited our discussion to studies that involve observation as a measure of instructional practices rather than those that rely solely on self-report data. Using surveys alone to provide insights into classroom practices is problematic for several reasons. As Ball and Rowan point out (2004, p.4), "key descriptions of practice used in survey instruments are seldom understood uniformly by respondents." In addition, it is difficult for teachers to accurately remember classroom events and interactions (NCES, 2003), and this can lead to their inadvertently misrepresenting their practice (Ball & Rowan, 2004). This issue is made salient by the discrepancy between teachers' responses to questionnaire items and actual classroom observations in the TIMMS video study (NCES, 2003). For example, 86% of the U.S. eighth grade teachers surveyed reported that the videotaped lesson was consistent with current ideas about teaching and learning mathematics yet the observations suggest that the goal of the observed lessons was to learn and use procedures (NCES, 2003).

Although there have been many studies in the past 15 years (discussed earlier in this chapter) that have linked the use of particular curricula to student achievement or have analyzed the ways in which teachers and their students have enacted mathematical tasks or curricula, few studies have connected the curriculum (or tasks) *as enacted* with student learning or achievement. Three studies cited below provide evidence that the cognitive demands of the mathematics tasks in which students engage are related to student learning.

Evidence gathered across scores of middle school classrooms in four QUASAR middle schools has shown that students who performed the best on project-based measures of reasoning and problem solving were in classrooms in which tasks were more likely to be set up <u>and</u> implemented at high levels of cognitive demand (Stein & Lane, 1996; Stein, Lane, & Silver, 1996). In these classrooms a teacher's success in enacting tasks in ways that maintained the rigor of the tasks was related to the processes identified in the right-hand column of Table 8.2. For students in these classrooms, having the opportunity to work on challenging tasks in a supportive classroom environment translated into substantial learning gains on an instrument specially designed to measure high level thinking and reasoning processes. It is worth noting that the school that achieved the highest student learning gains (Site A), and the greatest percentage of tasks that were set-up and enacted at a high level, was using the standards-based *Visual Mathematics* curriculum. Results from QUASAR also show that students who had the lowest performance on project assessments were in classrooms where they had limited exposure to tasks that required thinking and reasoning (Stein & Lane, 1996).

The results of the 1999 TIMSS video study provide additional evidence of the relationship between the cognitive demands of mathematical tasks and student achievement. In this study, a random sample of 100 8th grade mathematics classes from each of six countries (Australia, the Czech Republic, Hong Kong, Japan, the Netherlands, Switzerland) and the United States, were videotaped during the 1999 school year. The six countries were selected because each performed significantly higher than the U.S. on the TIMSS 1995 mathematics achievement test for eighth grade (Stigler & Hiebert, 2004). The 1999 study revealed that the higher-achieving countries implemented a greater percentage of *making connections* tasks in ways that maintained the demands of the task. With the exception of Japan, higher-achieving countries did not use a greater percentage of high-level tasks than in the U.S. All other countries were, however, more successful in not reducing these tasks into procedural exercises. Hence, the key dis-

tinguishing feature between instruction in the U.S. and instruction in high achieving countries is that students in U.S. classrooms "rarely spend time engaged in the serious study of mathematical concepts" (Stigler & Hiebert, 2004, p. 16).

In a recent study Boaler and Staples (in press) report the results of a five-year longitudinal study of 700 students in three high schools. Students at one high school, Railside, used a standards-based curriculum designed by teachers around key concepts (e.g., What is a linear function?) and featuring groupworthy tasks drawn from curricula such as *College Preparatory Mathematics* (CPM) and the *Interactive Mathematics Program* (IMP) and a textbook of activities that use algebra manipulatives. The students at the other two high schools used conventional curricula. The researchers report that students at Railside achieved at higher levels than those at other schools. In particular, by the end of the second year Railside students significantly outperformed all other students in a test of algebra and geometry.

Boaler and Staples (in press) indicate that one factor contributing to the success of students at Railside was the high cognitive demand of the curriculum and the teachers' ability to maintain the level of demand during enactment through questioning. According to the authors, "the support that teachers gave to students did not serve to reduce the cognitive demand of the work, even when students were showing signs of frustration. . . . At Railside, teachers were highly effective in interacting with students in ways that supported their continued thinking and engagement in the core mathematics of the problems" (p. 27). In addition, the authors point to other sources of the Railside success story that include the strong commitment of teachers to the advancement of equity, the development of a curriculum that enhances success for *all* students by including problems that value a range of abilities, and the accountability placed on students for their own learning and that of their peers. Hence, Boaler and Staples conclude that although the curriculum played a part of the success of Railside students, "at the heart of this system is the work of the teachers, and the numerous different equitable practices in which they engaged" (p. 31).

The results of a study of middle school curriculum being undertaken by the Center for the Study of Mathematics Curriculum[16] provides additional evidence of the importance of the learning environment in student achievement. In this study, Tarr et al. (in press) investigated the impact of three factors on student achievement: curriculum type (conventional vs. standards-based), fidelity of curriculum implementation, and the nature of the learning environment.[17] The study included more than 4200 students in grades 6–8 from 11 middle schools across 6 states. The curricula included both standards-based curricula (i.e., *Connected Mathematics*, *Mathematics in Context*, and *Math Thematics*) and conventional curricula from commercial publishers (e.g., Addison Wesley, Glencoe, Harcourt Brace).

The study's findings suggest that student achievement in mathematics cannot be predicted solely by the type of curriculum used or by the fidelity of implementation of a curriculum. However, student achievement in mathematics could be predicted by the nature of the classroom environment. Specifically, a standards-based learning environment was associated with higher performance on an assessment of thinking, reasoning and problem solving regardless of the curriculum being used. A standards-based learning environment, however, was more frequently found in classrooms that used standards-based curricula. Particularly interesting is the finding that achievement was highest among students who experienced a standards-based curriculum in a standards-based learning environment over two consecutive years.

The findings of this study suggest that the learning environment is a critical factor in student learning and that standards-based curricula are most effective when the normative practices are in place that promote understanding, that is, learning is viewed as problem solving, alternative strategies and perspectives are discussed publicly, and explanations are given to support conjectures and approaches.

In addition to the above studies that have linked observed instructional practice and student achievement across many classrooms, there have been several smaller scale studies, focused on students' performance in arithmetic in the primary grades, that provide additional evidence of the connection between in-

[16] The Center for the Study of Mathematics Curriculum (CSMC) is one of the Centers for Learning and Teaching Initiative funded by the National Science Foundation. The goal of this initiative was to encourage cross-institutional collaboration on the preparation of future K-12 STEM leaders and on research on critical issues in the field. CSMC is a collaboration of the University of Missouri, Michigan State University, University of Chicago, Horizon Research, Columbia Public Schools, Grand Ledge Public Schools, and Kalamazoo Public Schools.

[17] The authors use the term "Standards-Based Learning Environment" (SBLE) to describe classrooms where students make conjectures and explain responses and teachers use students' thinking as the basis for instruction and encourage multiple perspectives and strategies.

struction and learning (Carpenter et al, 1989; Hiebert & Wearne, 1993; Wood et al., 1991). These studies show that students in classrooms that used standards-based curricula that included on-going opportunities to engage with high-level tasks outperform students who are exposed to more conventional curricula and instructional approaches. For example, in a study of instruction and learning in second grade classrooms, Hiebert and Wearne (1993) report that students in classrooms that used an alternative to the more conventional textbook program (i.e., a standards-based curricula) showed higher levels of performance than students in classrooms that used a conventional curricula. The alternative program used contextualized problems, encouraged the use of different representational forms and different solution strategies, and allowed for a public discussion and sharing of students solution strategies (Hiebert & Wearne, 1993). Thus the authors conclude that, "instructional tasks and classroom discourse mediate the relationships between teaching and learning" (p. 420).

One question raised by these studies is 'how do mathematical tasks and discussions around those tasks influence learning?" One explanation is that students learn mathematics by solving problems and by listening to what the teacher and their peers tell them. More likely, however, is that teaching influences students' cognitive processes of thinking which in turn influences their learning (Carpenter & Fennema, 1988; Hiebert & Wearne, 1993; Wittrock, 1986). According to Hiebert and Wearne (1993, p. 421) "certain kinds of instructional tasks and discourse encourage more productive ways of thinking."

The studies reviewed in Section One and this section can be seen as complementing one another. By focusing on tasks, discourse, and students' opportunities to learn, the studies reviewed in this section help to uncover the mechanisms by which curricula might improve student performance. In this way these studies begin to explain why two different classrooms using the same curriculum might result in different levels of student performance. The larger scale studies in Section One, on the other hand, are useful for suggesting what teachers on average might be expected to accomplish using the newer curricula and thus we learn something about the feasibility of implementing them at scale.

SUMMARY AND CONCLUSIONS

We begin by summarizing and in some cases elaborating on the major points that were surfaced in Sections One–Five.

Curricula Differ in Significant Ways

In Section One, we concluded that the analyses of curriculum materials completed to date suggest that the mathematics curriculum materials available today differ significantly from each another, with the most consistent differences found between those that we have labeled standards-based vs. conventional. Standards-based curricula embody an approach to learning that focuses on the students' active construction of important ideas and concepts while conventional based curricula, by and large, present content directly and expect the teacher to explicitly teach students the skills, concepts and procedures that are the goal of the lesson. Our review also pointed to the need for evaluators to clearly articulate the criteria by which they judge the quality of curricula. As shown by the ratings in Appendix A, the same curriculum fares very differently depending on the criteria by which it is judged.

These Differences Impact Student Learning

The pattern of findings associated with the comparative, mostly quantitative, research discussed in Section One suggests that the above differences matter, at least with respect to how much computational and conceptual knowledge students gain relative to each other when one group is taught using standards-based and the other using conventional curricula. Students taught using standards-based curricula tend to "keep up" with their conventionally taught counterparts with respect to computational knowledge but to surpass them in conceptual knowledge and their ability to solve non-routine problems. However, all students tend to do best on tests that align with the way they were taught, giving conventionally taught students a slight edge on traditional standardized tests and standards-taught students a considerable edge on measures of thinking, reasoning, and problem solving.

Kilpatrick (2003) has suggested, and we agree, that findings such as these appear to be oriented toward reassuring the public that the new standards-based curricula are not harming students more than assessing what students truly appear to be learning from them. Regardless, the findings that curricula differ in significant ways and that these differences impact student learning point to the role that healthy discussions of values (what kind of mathematics should students be learning?) must play in decisions to adopt one curriculum over another.

From a research—or knowledge-building—perspective, these findings feel somewhat unsatisfy-

ing. Knowing how much students learn may be less important than knowing what and how they learn. For example, an emerging insight from some of the studies cited in Section One that included qualitative data gathering (e.g., Huntley et al., 2000) is that students who learn and practice symbolic skill manipulation under the auspices of a standards-based curriculum may learn such skills in a qualitatively different way than do students who are taught skills in a direct, sequenced, and structured manner. We need investigations to understand more about the forms of knowledge and understanding that students develop in standards-based versus conventional curricular approaches, and about how the particular approaches support this development. Students most likely do not simply develop more or less knowledge but rather acquire knowledge, beliefs and understandings that differ in important ways including how they become available for use at later points.

No Curriculum is Self-Enacting

The studies reviewed in Sections Two and Three reveal the variation to the written curriculum that is introduced once human interaction enters the picture. Section Two focused on the interpretive processes by which teachers "read" curriculum; Section Three focused on the transformative forces that are unleashed once curricular materials are actually used in the classroom. The research and conceptual ideas introduced in both sections suggest that—while not self-enacting—curricula that focus on the development of specified skills and procedures offer less room for interpretation and transformation than do curricula that focus on reasoning, problem solving, and strategy development and depend on the actions of both students and teachers to bring their designs to fruition.

Counterarguments that have or might be made to this statement include the observation by Mathematically Correct that some of the so-called conventional curricula have become so overlaid with suggestions for problem solving activities and group work that teachers now have to make decisions regarding what to cover and how to prioritize their time between teacher-directed instruction and these "constructivist"-based activities. On the other hand, some might argue that technology-enhanced standards-based curricula such as the *Cognitive Tutor* offer a narrower berth for teacher interpretation because of the large amount of instructional time that occurs directly between the student and the computer.

Standards-Based Curricula are Challenging to Enact Well

Along with their unstructured learning space and room for variable enactment, standards-based curricula offer more enactment challenges to the average teacher. The studies cited in Section Three demonstrate the ways in which tasks from standards-based curricula can be distorted such that they no longer embody the vision or goals that the developer intended. Using these curricula in ways that unlock the potential that their developers envisioned requires considerable knowledge and time on the part of the teacher, as well as a philosophical orientation toward teaching and learning that aligns with that of the developers. Other factors that influence the level of success that can be expected from using standards-based curricula are identified and discussed in Section Four.

The high degree of variation associated with the enactment of standards-based curricula point to the need to interpret studies of student learning from such curricula with caution. Given the high degree of "slippage" associated with the enactment of high-level tasks, it is unclear whether limited student learning should be attributed to the materials or the manner in which they were implemented in the classroom. This is less often the case with interpreting studies of conventional curricula.

The Success of Standards-Based Curricula is Influenced by Multiple Factors

Sections Four and Five identify factors within and outside the classroom that impact the ease with which a successful implementation of a standards-based curriculum can be achieved. The studies in these sections are important to teachers because they uncover the variety of contextual factors that often accompany successful implementation of standards-based curricula but that are sometimes not overtly articulated as supporting factors. The studies that looked closely at particular teaching interactions in the classroom provide a level of detail that is needed by teachers who wish to implement tasks from standards-based curricula. From a research perspective, more fine-grained studies of classroom implementation provide a clearer, more complete picture of how and under what conditions standards-based curriculum lead to improvements in students' learning.

* * *

We began this chapter with the introduction of a framework that illustrated various phases of cur-

riculum use. Uncovering how curriculum influences student learning, we argued, would not be possible without reviewing what is known about how the curriculum is mediated before and in the process of making its way to students. By reviewing and summarizing the implications of studies that lay at various markers along this temporal pathway, we have identified and described—not only whether—but also *how* curricula influence student learning. This review of the research on how curriculum influences student learning has illuminated the vast conceptual territory that lies between the curriculum as a designed object and student learning.

Our claims rely on studies that we have patchworked together to form a longer chain of reasoning regarding the phases through which curricula traverse. In the patchwork process, we have had to gloss over inconsistencies in conceptualizations, definitions of terms, and points of focus that existed across the various studies. In the chapter we call for the field to establish more agreement regarding what to focus on and how so that studies can be accumulated and build toward a solid understanding of how curricula are transformed and eventually influence student learning. Studies that are conducted to examine the entire chain—from materials analyses to teacher interpretation to curricular enactment to student learning—would also add considerably to our knowledge base.

Looking toward the future—including studies that might help curriculum developers improve their materials—perhaps the most pressing question is how to combine the best of both conventional and standards-based curricula into a more unified and balanced approach. How can teachers effectively teach procedural skills in the context of the open-ended, problem-based forms of instruction that characterize standards-based curricula? Standards-based lessons that encourage a variety of ideas, solution strategies, and forms of representation have the advantage of engaging students in thinking and learning to justify and reason. However, they also have the disadvantage of not converging neatly into a common core of knowledge that all students share and know—especially not in any predetermined time frame, be it a lesson, a grading period, a year, or in time for a high-stakes test. Making sure that all students eventually reach clarity and closure on important mathematics ideas and procedures is not trivial in this form of instruction (National Research Council, 2001).

The limitations of conventional curricula that focus too narrowly on procedural skill have been well documented; yet there are proficiencies that students who are exposed to those curricula gain. Learning how to incorporate elements of that learning into the curricula of tomorrow will be an important task. Given the ambition of the standards-based curricula—both in terms of the depth of student learning for which they aim and the numbers of teachers they hope to influence—we need to get much smarter about how we design studies to help the continuing evolution of those curricula.

Although we feel as though this chapter brings some conceptual order to the territory that lies between curriculum materials and student learning, the territory of the factors represented in the oval in Figure 8.1 is much less well conceptualized. As discussed in Section Four of this chapter, these factors have been supported by a host of studies, however, most studies looked at one, or at most two, factors in isolation from the others. Missing is research that systematically relates the factors to one another in a conceptually coherent manner. For example, we know that teachers' knowledge and beliefs influence how they interpret curricular materials and how they enact them in the classroom. However, we know little about how this knowledge and beliefs are influenced by context, including the informal communities in which teachers talk about mathematics and, most importantly, negotiate the meaning of new curricula. Moreover, we know little about how different features of curricula (how transparent their goals are; how much information they provided about possible student responses to their tasks) are related to various levels and kinds of teacher knowledge.

The research reviewed herein points to the challenges that most teachers face in learning to implement standards-based curricula well. There is beginning to be a body of research that examines *how teachers learn* through implementing these new curricula. We have not reviewed this research as it did not directly bear on the question of how curricula influences student learning. Nevertheless, we feel that it is an important component of the conceptual landscape that sits between the design of materials and student learning. If teachers are the mechanism through which curriculum becomes transformed and goes on to influence students, well-designed studies on what and how teachers learn from using these materials would form an important part of the overall picture.

On a related note, because these new standards-based curricula have been placed into the role of change agent, another kind of conceptual work is suggested as well: How teacher learning from curricular materials might be expected to happen at scale within schools and districts. Cobb et al. (2003) have pointed to a bifurcation of the research literature in this regard with one body of literature on professional development and another body on organizational/structural

facilitators and constraints to instructional improvement. With few studies that bridge the two, as a field we are left with decontextualized knowledge about effective professional development and knowledge about organizational supports for change that fails to make contact with the particular needs of teacher learning in mathematics. Thus, we need more studies that systematically integrate schools and districts as settings for curriculum implementation and what we know about the kind of teacher learning required to enact these curricula well.

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Appendix A

Ratings of Various Curricula by the U.S. Department of Education, AAAS, and Mathematically Correct

DOE: Curricula identified for recognition as Promising or Exemplary
AAAS: Middle school curricula identified as Satisfactory or Unsatisfactory
MC: Overall ratings of curricula

Curriculum	Level	Standards-Based (SB) or Conventional (C)	DOE	AAAS	MC
Everyday Mathematics; SRA/McGraw Hill	El	SB	Promising		2nd grade: C 5th grade: C–
Investigations in Number, Data, and Space; Scott Foresman	El	SB			2nd grade: F 5th grade: F
Math Advantage K–6; Harcourt Brace	El	C			2nd grade: B 5th grade: B–
Math in My World; McGraw Hill	El	C			2nd grade: B+ 5th grade: B–
Math K–5; Scott Foresman/Addison Wesley	El	C			2nd grade: B+ 5th grade: B–
MathLand	El		Promising		
Number Power (supplemental)	El	SB	Promising		
Saxon Math	El	C			2nd grade: B 5th grade: B+
Silver Burdett Ginn Math	El	C			2nd grade: B 5th grade: B
SRA Math; McGraw Hill	El	C			2nd grade: A 5th grade: A–
Connected Mathematics Project (CMP); Prentice Hall	MS	SB	Exemplary	Satisfactory	F
Heath Mathematics Connections; DC Heath & Co.	MS	C		Unsatisfactory	
Math Advantage; Harcourt Brace	MS	C		Unsatisfactory	B
Mathematics: Applications & Connections; Glencoe/McGraw Hill	MS	C		Unsatisfactory	B
Mathematics in Context (MiC); Holt, Rinehart, & Winston	MS	SB		Satisfactory	
Mathematics Plus; Harcourt Brace & Co.	MS	C		Unsatisfactory	
MathScape: Seeing and Thinking Mathematically; Glencoe/McGraw Hill	MS	SB		Satisfactory	
MathThematics (STEM); McDougal Littell	MS	SB		Satisfactory	D+
Middle Grades Math; Prentice Hall	MS	C		Unsatisfactory	B
Middle School Math; Scott Foresman/Adison Wesley	MS	C		Unsatisfactory	B
Middle School Mathematics Through Applications Project (MMAP; unpublished)	MS	SB	Exemplary		

Curriculum	Level	Standards-Based (SB) or Conventional (C)	DOE	AAAS	MC
Passport Series; McDougal-Littell	MS	C		Unsatisfactory	Passport to Algebra & Geometry: A Passport to Math: C
Saxon Math	MS	C		Unsatisfactory	Alg ½: A Math 87: C
Transition Mathematics (Scott Foresman)	MS			Unsatisfactory	
Cognitive Tutor	MS/HS	SB	Exemplary		
College Preparatory Mathematics (CPM)		SB	Exemplary		
Contemporary Mathematics in Context (Core-Plus)	HS	SB	Exemplary		
Interactive Mathematics Program (IMP); Key Curriculum Press	HS	SB	Exemplary		
University of Chicago School Mathematics Project Integrated Mathematics, Grades 7–12; Prentice Hall	HS	SB	Promising		